BROACHING PRACTICE

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A TREATISE ON THE COMMERCIAL APPLICATION OF THE BROACHING PROCESS INCLUDING DIFFERENT TYPES OF BROACHING MACHINES, THE DESIGN OF BROACHES AND EXAMPLES FROM PRACTICE ILLUSTRATING BROACHING METHODS

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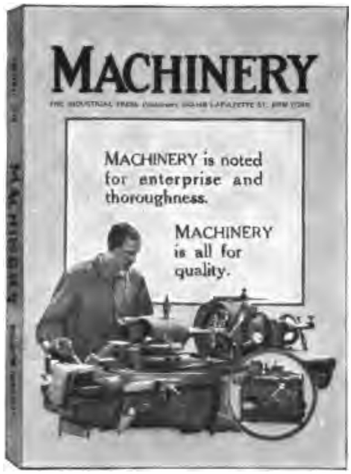
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PREFACE

FOR many years, broaching has been employed for cutting keyways and machining holes to a variety of shapes, but this method attracted comparatively little attention until extensive developments began to take place in the machine-building field, and especially in connection with the manufacture of automobiles. While machines have been used for broaching for many years, they were not in common use until about 1900, when the automobile business developed rapidly. Then broaching began to replace other machining processes in the production of certain duplicate parts, because of the accuracy and efficiency of the broaching method, especially for finishing holes of irregular shapes. At the present time the broaching machine is used extensively, not only by automobile manufacturers but by companies building a large variety of other products.

This treatise covers the three important elements in broaching practice; namely, the broaching machines, the design of the broaches or cutting tools, and the application of the broaching process to commercial work. Examples of broaching were obtained from plants using broaching machines for conducting regular manufacturing operations. Since these examples include many classes of work and represent a great diversity of requirements in regard to size and shape, they not only indicate the possibilities of this process but show just how this efficient method of machining can be applied under different conditions. Some of these examples from practice were previously published in MACHINERY and the author is indebted to the contributors of these articles as the material thus obtained made it possible to prepare a more comprehensive treatise.

E. K. H.

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CHAPTER I

PRINCIPLES OF THE BROACHING PROCESS

PRIOR to the period of intense activity in American industry, which was created by the war, broaching had demonstrated its practicability in many different manufacturing plants throughout this country and abroad; but the urgent demand for increased efficiency in the manufacture of munitions of war led to many improvements in broaching and to the application of this method in lines of work that had formerly been handled by slower and more expensive methods. As a typical example of this kind, the rifling of gun barrels on broaching machines may be mentioned. Formerly it required from twelve to sixteen hours to machine the grooves in a barrel, but when this work was put on broaching machines, the rate of production obtained was twelve barrels per hour. Another important factor in this connection was the fact that the operation of a broaching machine is so simple that unskilled labor could be utilized, which became a matter of great importance when the exigencies of war-time had greatly increased the demand for all classes of skilled factory employes.

The advantages of the broaching process are speed, interchangeability of work, adaptability to irregular forms, employment of comparatively unskilled labor, and adaptability to a great variety of work. The chief disadvantage is the high cost of broaches and the uncertainty of their life. One broach may cut 20,000 holes while another made of the same steel and hardened in the same way may not cut 2000. While broaching is chiefly applied to interior work, exterior work is also being successfully done, and one of

the possibilities is the broaching of spur gears when the quantity of duplicate gears is large.

Principles of Process. Briefly defined, the process in internal broaching consists in machining holes in castings or forgings by drawing or pushing through the rough cored or drilled hole one or more broaches having a series of teeth which increase slightly in size from one end of the tool to the other, and successively cut the hole to the required form. Broaching is especially adapted to the finishing of square, rectangular or irregular-shaped holes. It is also applicable to a wide variety of miscellaneous work, such as the cutting of single or multiple keyways in hubs, forming splines, cutting teeth in small internal gears and ratchets, etc.

Pull and Push Broaching. There are two general methods of broaching: One is by pushing comparatively short broaches through the work, usually by means of a hand press, a hydraulically operated press, or an ordinary punch press. With the other method, a special broaching machine is used, and the broach, which is usually much longer than a "push broach," is pulled through the work by means of a screw forming part of the machine. Push broaches must necessarily be quite short to prevent excessive deflection; consequently it is often necessary to force several broaches through the work. The longer broaches which are pulled through in regular broaching machines commonly finish parts in one passage, although a series of two or more broaches are often used for long holes, or when considerable stock must be removed. Comparatively short broaches are sometimes used, because they are easier to make, are not warped excessively in hardening and are easier to handle. Two or more parts can frequently be finished simultaneously on a regular broaching machine, the pieces being placed one against the other, in tandem.

Example of Broaching. A simple example of broaching by drawing the broach through the work is illustrated by the diagrams, Fig. 1. A square hole is to be broached in the hub of a gear blank, this being a sliding gear (such as is used in automobile transmissions) that is to be mounted

upon a square driving shaft. Prior to broaching, a hole is drilled slightly larger in diameter than the width of the square. The starting end of the broach, which at first is detached from the machine, is passed through the drilled hole in the blank, which rests against the end of the broaching machine. The end of the broach is then fastened to the "pull bushing" by a key *A* (which fits loosely to facilitate its removal), and the machine is started. By means of a powerful screw the broach is drawn through the hole in the gear blank and this hole is gradually cut to a square form

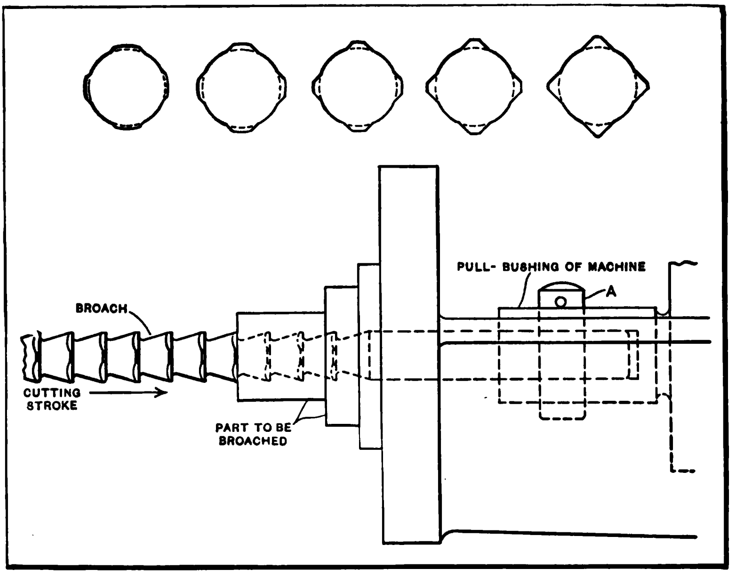

Fig. 1. Diagram Illustrating Method of Broaching a Square Hole

by the successive action of the teeth. The process is illustrated by the enlarged diagrams at the top of the illustration.

The first few teeth take broad circular cuts which diminish in width so as to form a square-shaped hole. Of course, it will be understood that for cutting a hexagonal, round, or other form of hole, a broach of corresponding shape must be used. The blank to be broached does not need to be fastened to the machine, but is simply slipped on the broach or a work bushing, in some cases, in a loose manner. As soon as the broaching operation begins, the

work is held rigidly against the end of the machine or fixture, when the latter is used.

From the preceding description of the broaching process, it will be seen that the function of the broaching machine is to draw the broach through the work at the proper speed.

General Classes of Work that can be Broached. Formerly, broaching was regarded purely as a means of finishing various shaped openings, but as previously mentioned, subsequent experience in the application of this process has shown that it can also be successfully employed for finishing outside surfaces of the work. In broaching an outside surface, the hollow broach used for this purpose is held in a fixed position and the work is pulled through the tool. The result secured by having each tooth of a broach slightly higher than the preceding one is equivalent to feeding a single tool into a revolving piece of work at a specified rate of feed per revolution. The degree of taper of the broach, which is usually expressed in inches per tooth, varies according to the nature of the work to be cut, the length of the work, and the construction of the machine on which the job is done. The average taper per tooth is 0.003 inch. In making broaches, the form of the teeth is also modified to meet the requirements of the work; for instance, it may be desirable in some cases to nick the teeth to assist in breaking chips, or to modify the amount of under-cut on the teeth to give them a smooth cutting action. At the end of the tapered section, it is the usual practice to have about five teeth of the same height, the purpose of this straight section of the broach being to finish the surface that was roughed out by the last tooth on the tapered section of the tool.

In a majority of cases, the cross-section of the broach is made of the same shape and size as the outline of the work that is to be broached; but in the case of unusually difficult operations, it may be found advantageous to use two or more broaches successively—as many as five broaches being used in series in some cases. Broaching machines have been used on such a variety of work that the making of general statements is difficult, but a fairly representative idea of

the applications of this machine shop method will be gathered from Figs. 1 and 2, Chapter IV and Fig. 3 of the present chapter. It may be stated that typical examples of internal work are the finishing of square, round, and other shaped openings, the cutting of keyways, spline grooves, etc., and cutting the teeth of internal gears.

External broaching is usually employed for finishing the outer surface of a piece of work to some desired form, the operation being quite similar to certain jobs that are generally performed on milling machines. One example of this kind is in the making of serrated rolls for use on textile machinery. It may be stated that as a general proposition it is not feasible to make either internal or external broaches over 6 inches in diameter.

Accuracy Attained in Broaching. The degree of accuracy which can be attained in broaching is largely dependent upon the amount of support furnished by the surrounding metal to those points on the work where the broach is cutting. In all cases of the cutting of metal, there is a tendency for the work to spring away from the tool unless it is prevented from so doing by some adequate means of support; and this holds true in all classes of broaching. The amount of distortion produced in this way is usually quite small, and in many cases the slight inaccuracy so introduced is not a matter of importance. To any experienced mechanic, it will be a self-evident fact that the highest degree of precision cannot be expected in work produced under the conditions that obtain in broaching; but it will be of interest to note in this connection, that where either the work or the work-holding fixture affords adequate support to resist the tendency to spring the work away from the cutting edges of the broach, it is possible to keep within limits ranging from 0.001 to 0.002 inch, and a broach will cut several thousand pieces having this degree of accuracy before it becomes sufficiently worn to affect the results obtained by it.

Provision for Sharpening Broaches. Obviously it is a matter of importance to design the teeth of a broach so that provision is made for grinding to resharpen the cutting

edges without reducing the diameter of the tool. This result is attained by providing a land on the top of each tooth, so that when the cutting edge becomes dull, grinding the front face of the tooth brings it back to a condition of sharpness without affecting the diameter. In referring to the form in which broaches are made, it was mentioned that the usual practice is to leave five or six teeth of uniform size at the end of the tapered section of the broach; and as sharpening of the teeth continues, the land will gradually be reduced until finally a point is reached where the height of the teeth begins to decrease with further grinding. Then the method of procedure is to grind down the first straight tooth so that it becomes the last one on the tapered section of the broach, and by continuing this practice the number of straight teeth is gradually reduced until there is only one of the straight teeth left. When the land of this last straight tooth has been ground away, the broach is no longer fit for service.

In order for a broach to perform its operation satisfactorily, it is only necessary to have one tooth of the full size at the rear end; hence, the successive reducing of five straight teeth to the last one of the tapered series affords considerable leeway for sharpening. Various degrees of success have been obtained in swaging the teeth of broaches along their back surface in order to increase the diameter sufficiently to allow a tool that has been completely used up to be reground to its original size; but experienced broach manufacturers do not recommend this practice of salvaging. Broaches are usually made of a good grade of carbon steel. Some users specify high-speed steel, but this practice seems unjustifiable owing to the relatively low cutting speed that is employed. This speed averages from five to six feet per minute, with a return speed at a ratio of 5 to 1, and quite evidently this rate of cutting is not high enough to justify the greatly increased expense of high-speed steel as compared with that of carbon steel.

Coolants Used for Broaching. Owing to the diversity of conditions which exist in cutting various kinds of metal, it is necessary to use different coolants or lubricants to pre-

vent excessive heating of the broach and work, and also to afford a lubricating action that will overcome frictional resistance and consequent wear. In broaching cast iron and brass, it is generally found unnecessary to make any special provision of this kind, and in some shops aluminum is also broached dry, although it is better practice to use kerosene as a coolant. For many classes of work, a cutting emulsion made in accordance with the following formula will be found to give satisfactory results: Mix $2\frac{1}{2}$ pounds of soda ash and 3 gallons of mineral lard oil in 10 gallons of water, and after stirring thoroughly add 40 gallons more water. The mineral lard oil used in preparing this emulsion consists of one-third lard oil and two-thirds petroleum machine oil. On steel of ordinary hardness, mineral lard oil is used, because for this work it is necessary to obtain a combined cooling and lubricating action, and on particularly tough work, such as alloy steel, etc., it may be necessary to use white lead slightly thinned with linseed oil or kerosene.

Range of Work that can be Broached. Up to the present time, the maximum length of cut in broached work is about 80 inches. For broaching steel, experience has shown that the best results are not obtained where the heat-treatment has been conducted in such a way as to give the maximum degree of softness. It is recommended that the work be brought to a scleroscope hardness of from 32 to 40. If the metal is softer, it will tend to tear instead of cutting freely, and steel which shows a greater degree of hardness than the higher limit of the range that has been mentioned will rapidly destroy the broaches.

Importance of Adequate Illumination. Attention has already been called to the fact that the degree of precision obtained in the performance of broaching is not as high as that secured by certain other methods of machining. It is the high rate of output secured by this method which commends it to the favorable consideration of those manufacturers who have large quantities of parts on which a very high degree of accuracy is not essential. For such work, the greater output of the broaching machine more than offsets its failure to give an extremely high degree of accu-

racy. As it is the high rate of output in which most manufacturers are interested when they decide upon the use of broaching machines, attention is called to the close relationship that exists between the illumination of departments where broaching machines are operated, and the rate of output that is likely to be attained. As they are under the impression that the work done on these machines is rough in character, some manufacturers have reached the conclusion that any unoccupied corner is a good enough place in which to set up their broaching machines. Where such a practice is followed, it will often happen that a high price is paid for the utilization of such undesirable space, through the loss of production that is directly attributable to insufficient lighting, etc. This has been conclusively shown in cases where broaching machines have been transferred from an undesirable department to a department where the lighting conditions are more favorable.

Ordering Broaches. Users of broaching machines would do well to bear in mind that the cutting tools are always made to meet the special requirements of each job. It is impossible to order them from stock, as in the case of twist drills and other standard tools. Orders ought to be placed a sufficient length of time in advance of the date on which tools may be needed for use, so that the production department may rest assured that its requirements will be fulfilled at the proper time. Some manufacturers who have delayed the placing of orders under the impression that immediate delivery could be made, have found that the impossibility of having their orders promptly executed has caused expensive delays. Such delays have held up the work in subsequent departments because of the impossibility of performing broaching operations required on parts of the product. In ordering broaches for a given job, it is important to submit adequate information in regard to the local conditions that must be fulfilled. Data sent with such orders should include information covering the method used in preparing a hole for broaching, the material from which the work is made, the finished size of the hole to be broached, the limits of tolerance within which the work must be

held, and the rate of production required. It is a good practice to send samples of work with tool orders, so that the broach maker is able to experiment with a view to ascertaining the correct amount of under-cut, the kind of lubricant, etc., that will give the most satisfactory results.

Three Methods of Broaching Spiral Grooves. On work where it is required to broach spiral grooves or rifle grooves, or to perform other operations of this general character, any of three methods of procedure may be followed to obtain the required result. The most obvious of these is the practice of attaching the broach to what is known as a "master lead bar" in which grooves are cut that have the same spiral lead as those which it is required to broach in the work. This master lead bar and broach are so connected to the draw-head of the machine that they are free to rotate. Fixed pins which enter these grooves in the lead bar cause the proper amount of rotation during the stroke of the draw-head to provide for turning the broach sufficiently to give the grooves the desired spiral form.

Another method of more recent development, which is said to give satisfactory results, is to use a broach with the teeth arranged in spiral rows, and to provide what is known as a ball-bearing thrust plate on the front of the faceplate of the broaching machine. The work rests against the thrust plate, and as the broach starts to make its cut, the inclined side walls of the spiral teeth tend to rotate the work, because the broach is so secured to the draw-head that it cannot turn. Under such conditions, the elimination of frictional resistance through the use of the ball-bearing thrust plate between the work and the faceplate enables the work to be turned by the broach, to obtain the required spiral form for the grooves to be broached in the hole.

A third and quite similar method to the one just described is to use a ball-bearing coupling to connect the broach to the draw-head of the machine. This practice allows the broach to turn as it is drawn through the work, owing to the pressure of the inclined side walls of the teeth on the work instead of having the work turn relative to the broach as a result of the same influence.

Method of Connecting Broaches to the Pull-bushing. Three methods are quite commonly used for connecting broaches to the pull-bushing in the draw-head of a broaching machine. One of these is to use a threaded connection between the end of the broach and the bushing; another is to cut a key slot through the bushing and shank of the broach, so that a key may lock these two members together as previously mentioned; and the third method is to utilize a taper fit between the shank of the broach and the bushing. The selection of a method will depend somewhat on the character of the work. In many cases the broach must be removed from the draw-head after each operation has been completed, because it is necessary to pass the shank of the broach through the work and reconnect it to the draw-head, preparatory to the next actual cutting operation. Where this procedure is followed, the best form of connection is the slot and key, because it is an easy matter to pull out the key and remove the broach from the pull-bushing; and after the broach has been passed through the next piece of work, reconnection can be made with a minimum loss of time. Threaded connections are more commonly used in instances where the nature of the work is such that the broach does not have to be removed from the draw-head after taking each cut.

Reducing Idle Time of Machines and Operators. In broaching, as in other classes of machine work, it is desirable to reduce to a minimum the idle time of both the machines and their operators. It was with this idea in mind that double-head broaching machines were developed. A machine of this type which is manufactured by the J. N. Lapointe Co. is illustrated in Fig. 2. The design is such that the cutting and return strokes of the heads alternate, thus allowing the operator to remove a finished piece from one fixture and substitute a fresh blank while the other piece is being broached. As the return stroke of the spindle is made at approximately five times the speed of the forward stroke, plenty of time is allowed for the operator to remove the broached piece and set up a blank while the operation is progressing at the other side of the machine. A similar

machine built by the same concern is more fully described in the next chapter. On some classes of work it is desirable to utilize what is known as an oil-pan and support table of the type shown in this illustration. Such an equipment maintains accurate alignment of the broaches and avoids much of the danger of breaking a broach, in the event of some unusually severe condition of operation being encountered.

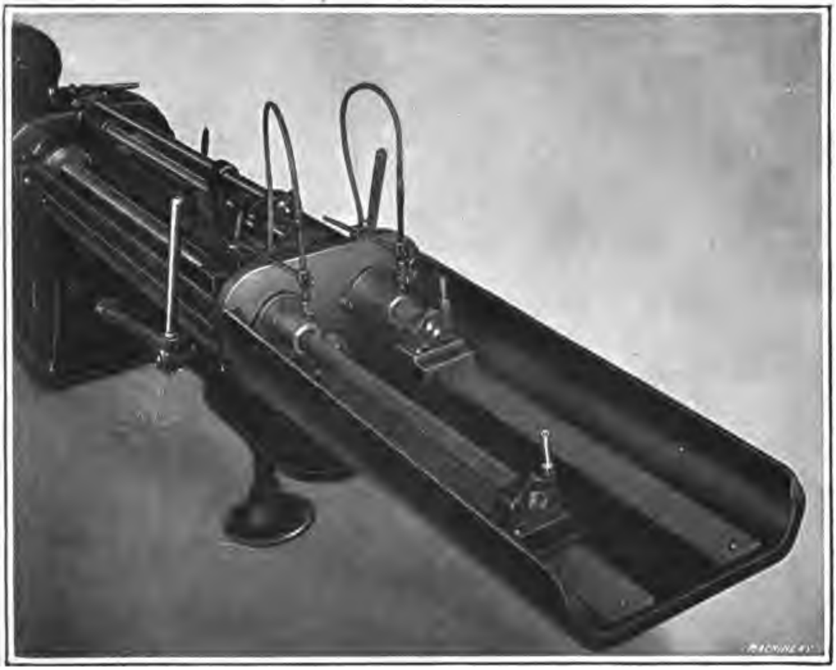

Fig. 2. Double-head Broaching Machine equipped with a Supporting Table and Slide to hold Outer Ends of the Broaches in Alignment

Time Required for Broaching Operations. Some typical broaching operations are illustrated in Fig. 3. The dimensions of these parts and the number broached per hour are given in the following:

Sample A: 3/4-inch square hole; sharp corners; 1 3/8 inch long; 50 per hour.

Sample B: 15/16-inch square hole; sharp corners; 1 1/2-inch long; 50 per hour.

Sample C: 1 3/8-inch square hole; sharp corners; 4 inches long; 15 per hour.

Sample D: 1 3/32-inch square hole; round corners; 2 inches long; 45 per hour.

Sample E: 1⅜-inch square hole; round corners; distance across corners, 1¾ inch; 1½ inch long; 45 per hour.

Sample F: ⅝-inch hexagon hole; 1⅜ inch long; 60 per hour.

Sample G: 1⅝-inch hexagon hole; 2 inches long; 45 pei hour.

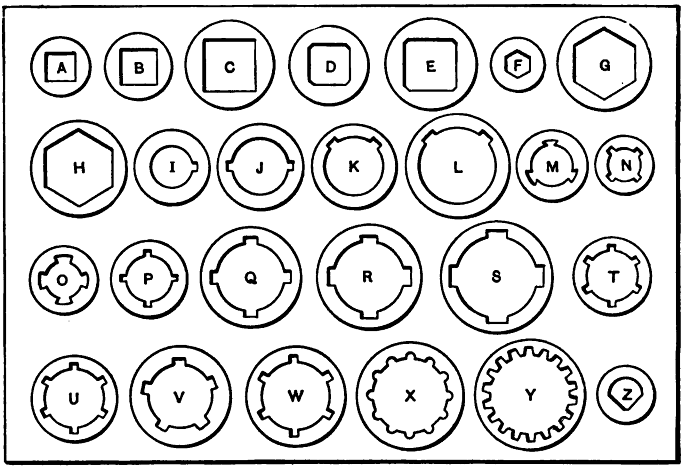

Fig. 3. Typical Examples of Broaching Operations

Sample H: 1¾-inch hexagon hole; 1½ inch long; 45 per hour.

Sample I: 1-inch hole; ¼ by ⅛-inch keyway; ½ inch long; 250 per hour.

Sample J: Two-spline hole; 1½ inch diameter; 5/16 by 5/32 inch splines; 1½ inch long; 90 per hour.

Sample K: Two ½- by ¼-inch keyways in 1½-inch holes 3 inches long; 45 per hour.

Sample L: 2-inch hole; ¾- by 5/16-inch keyways; 3 inches long; 45 per hour.

Sample M: Three-spline dovetail hole; 1⅛-inch diameter; outside diameter, 1⅜ inch; ½ inch long; 135 per hour.

Sample N: Four-spline 15/16-inch hole; splines ¼ by ⅛ inch wide; 1 inch long; 100 per hour.

Sample O: Four-spline dovetail hole; 29/32 inch; 2 inches long; 45 per hour.

Sample P: Four-spline hole; 1¼-inch diameter; 1⅝-inch outside diameter; width of spline, 5/16 inch; 3 inches long; 45 per hour.

Sample Q: Four-spline hole; 1¾-inch diameter; outside diameter, 2⅜ inches; splines 9/16 inch wide; 4 inches long; 15 per hour.

Sample R: .Four-spline hole, 1⅞ inch; keyways ¾ by 3/16 inch; 3 inches long; 20 per hour.

Sample S: Four-spline hole; 2⅛-inch diameter; outside diameter, 2½ inches; splines ⅞ inch wide; 2 inches long; 45 per hour.

Sample T: Six-spline 1 7/16-inch hole; outside diameter, 1 11/16 inch; width of spline, ⅜ inch; 4 inches long; 25 per hour.

Sample U: Six-spline hole; 1½-inch diameter; splines ⅜ by 3/16 inch; 1½ inch long; 45 per hour.

Sample V: Five-spline hole, 1 47/64 inch; outside diameter, 2 3/16 inch; width of spline, 7/16 inch; 3¾ inches long; 15 per hour.

Sample W: Six-spline hole; 1 13/16-inch diameter; splines ⅜ inch wide; outside diameter, 2 1/16 inches; 4 inches long; 15 per hour.

Sample X: Twelve-spline; 2-inch diameter; grooves ⅛ inch radius; ½ inch long; 180 per hour.

Sample Y: Internal gear; 18 teeth; 2⅛-inch hole; ½ inch face; 120 per hour.

Sample Z: ¾-inch semi-square; 1-inch corner diameter; 1 inch long; 40 per hour.

CHAPTER II

BROACHING MACHINES AND METHODS

A TYPICAL broaching machine is illustrated in Fig. 1. The broach is secured to a draw-head *A* which in turn is attached to the end of a large screw *B*. This screw passes through a phosphor-bronze nut which is held against endwise movement and is rotated through gearing connected with the belt driving pulley *C*. As the nut rotates, screw *B* is moved one way or the other, depending upon the direction of rotation. On the broaching or cutting stroke, the drive is from a pinion on the belt pulley shaft to a large gear (enclosed by guard *D*), which is connected to the screw operating nut by a clutch. On the return stroke, the clutch is shifted out of mesh with the large gear and is engaged with a smaller and more rapidly moving gear which rotates in the opposite direction.

The stroke of the machine is automatically controlled by two adjustable tappets mounted on a rod extending along the rear side. When either of these tappets is engaged by an arm which extends backward from the draw-head *A*, the rod upon which they are mounted is shifted. This movement of the rod operates the clutch, previously referred to, which reverses the motion of the nut on the screw. The stroke of the machine is regulated by simply changing the position of the tappets. The vertical lever *E* operates this same tappet rod and is used to start, stop or reverse the movement of the machine by hand. Cutting lubricant for the broach is supplied through the flexible tube *F*.

J. N. Lapointe Co.'s Duplex Broaching Machines. A duplex or double type of broaching machine is illustrated in Fig. 2. The distinctive feature of this machine is that there are two operating screws so that two broaches can

be used at the same time. The design of the machine is such that one head is being returned while the other is on the cutting stroke. As it is possible to disengage one of the operating screws, the machine can be changed into the

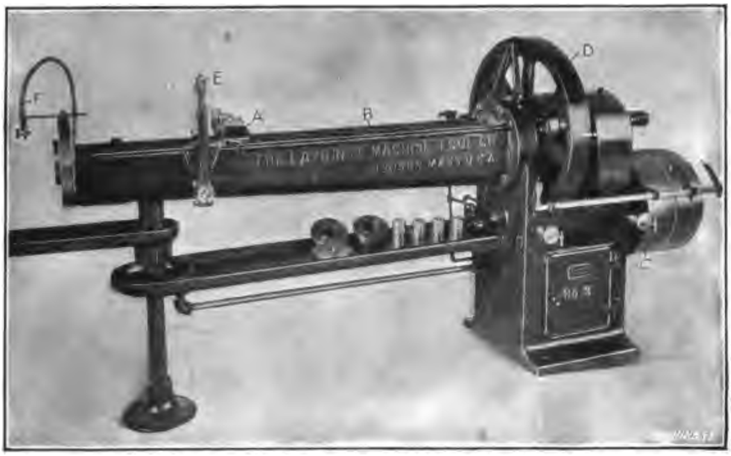

Fig. 1. Broaching Machine

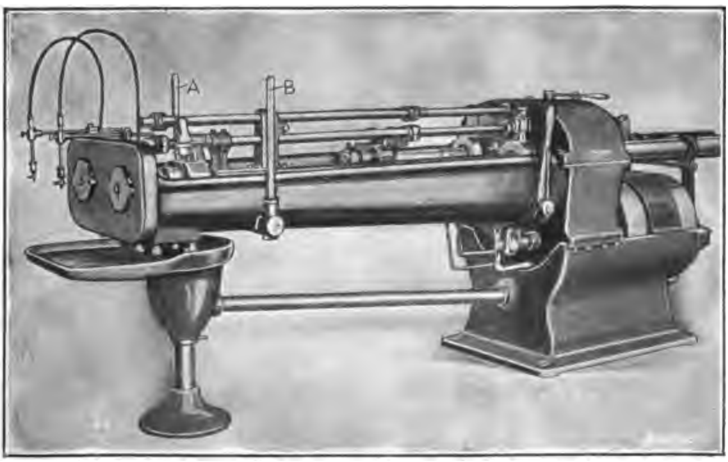

Fig. 2. Duplex Broaching Machine

equivalent of a single broaching machine if desired. Both operating screws are provided with individual trips for regulating the length of the stroke. These trips are mounted upon rods which are located above the operating screws.

Two broaching speeds are available, and two operating levers A and B are used to control the machine from either side. There is a pump and oil reservoir in the base of the machine to supply lubricant to the broaching tools. Two flexible tubes at the front end of the machine direct the cutting compound upon the broaches at the point where the cutting action takes place.

Means are provided for adjusting the stroke of the machine so that each screw operates on the same length of stroke. When making the adjustment, one of the sliding

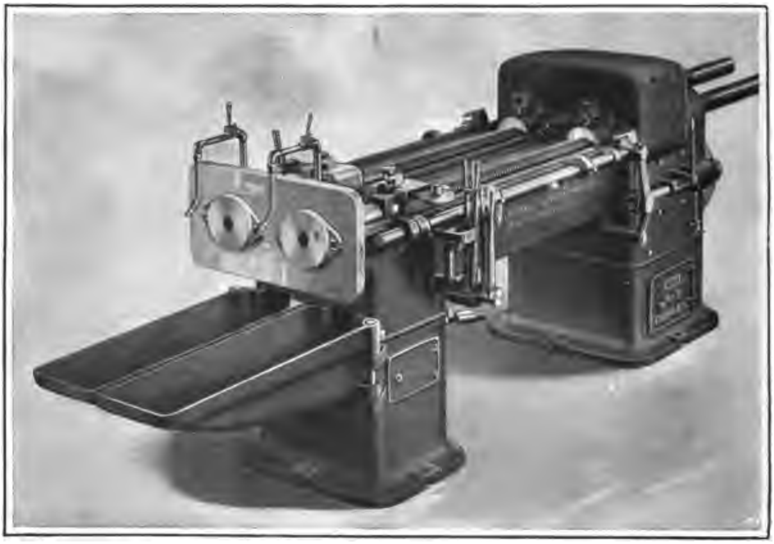

Fig. 3. No. 3 Duplex Broaching Machine

heads is brought into position ready for the cutting operation. The lever seen at the top of the gear-case is then moved sideways to disconnect this head. The operating lever on the machine is next shifted to the working position, and the other sliding head is moved to a position corresponding with the extreme length of stroke required. The stops are then set in this position and the stops for the other head are set in alignment with them. The lever on top of the gear-case is then shifted to bring the first head into operation. The travel of the sliding head on

the low speed is 3 feet per minute, and on the high speed, 6 feet per minute. The maximum stroke of the machine is 54 inches. It has a capacity for broaching holes up to 3 inches square.

The No. 3 duplex machine is shown in Figs. 3 and 4. It is adapted for use in factories where there are large quantities of work to be broached and where the conservation of floor space is important. The operation is con-

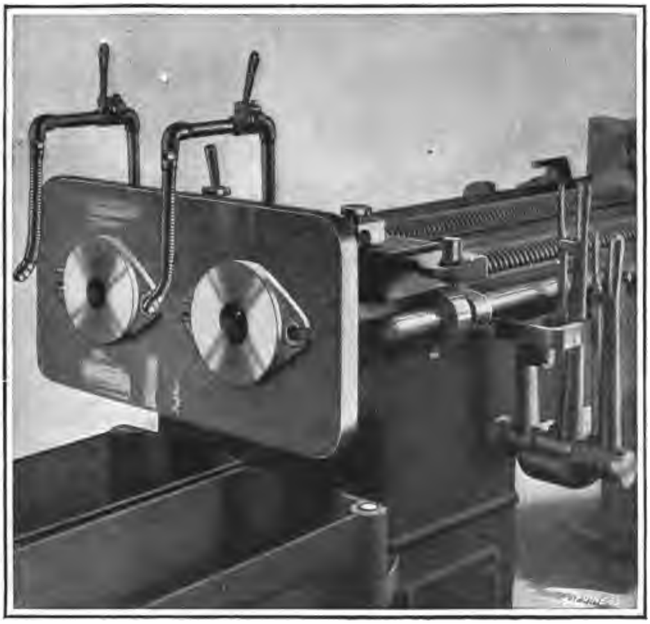

Fig. 4. Close-up View of the Operating Screws and Control Levers on Duplex Broaching Machine

trolled through a patented clutch which affords a positive drive. The actuating screws work entirely independently of each other, and may be operated separately or in unison. Provision is made for regulating the stroke of either screw so that two broaches of different lengths can be operated at the same time. Both screws are controlled by levers on the right-hand side of the machine, and the left-hand screw can also be controlled by a lever at the left-hand side. There are two cutting speeds provided by each screw,

namely, 49 and 74 inches per minute; and the return speed is 196 inches per minute.

All gearing is enclosed and the gears run in a bath of oil, an oil gage being provided on the side of the machine to show the amount of oil in the gear-case. Brakes act on the clutches, eliminating any chance of the screws over-running on the return stroke while operated at a high rate of speed. The gears are always in motion and running in the same direction. A pump supplies a steady stream of lubricant to the machine while broaching, oil being drawn from a reservoir located in the front pedestal. Sufficient

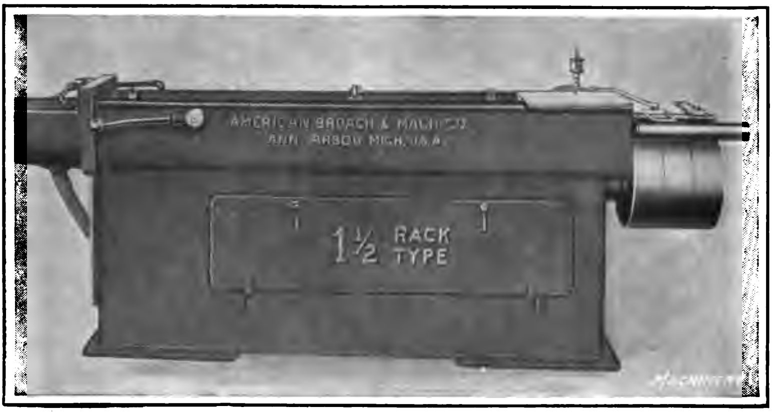

Fig. 5. Rack-operated Broaching Machine

capacity is provided on this machine for cutting, in steel, keyways up to 1½ inches wide, or for broaching square holes up to 3 inches across the flats. The maximum stroke is 50 inches, and adjustments can be made to suit special requirements of the work.

Rack Type Broaching Machine. The No. 1½ rack type broaching machine built by the American Broach & Machine Co., Ann Arbor, Mich., is illustrated in Fig. 5. The manufacturers claim that this machine is capable of more rapid operation than their screw-operated type of broaching machine. A special bronze worm-gear is keyed to the driving shaft, the worm and worm-wheel shown in Fig. 6

are encased, and run in grease. The main driving pinion engages with a D-shaped rack.

The machine is provided with a high-speed return motion which operates at double the speed of the cutting stroke. The loose pulleys shown in Fig. 7 are mounted on Hyatt roller bearings. There are no clutches employed on this machine, but an automatic brake band is provided which operates immediately when the sliding head reaches either

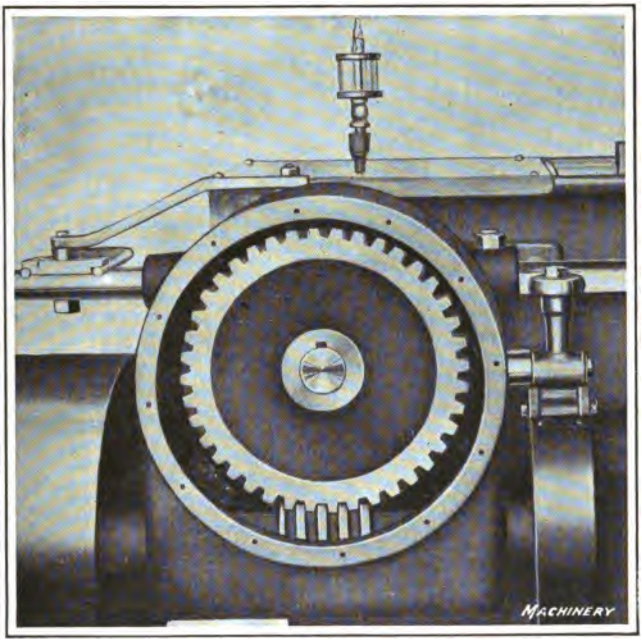

Fig. 6. Cap shown removed from Worm-wheel Housing

end of the stroke. This brake absorbs the momentum of the driving mechanism and enables the travel of the table to be controlled by automatic stops.

When using a broach 4 feet in length, the time required for the cutting stroke and the return of the broach to its starting position is from 28 to 30 seconds. The machine has a cabinet base which is fitted with shelves. The face of the base is finished within 2 inches of the foot and has two machined T-slots for attaching boring fixtures, an oil

trough or other attachments. An oil pump, which requires no priming, is furnished as standard equipment. It is claimed that the life of the rack-operated machine is lengthened because of freedom from twisting action.

Broaching in a Vertical Press. Fig. 8 shows an example of "push broaching," comparatively short broaches being forced down through the work by means of a hydraulic press. The operation is that of broaching the holes in axle

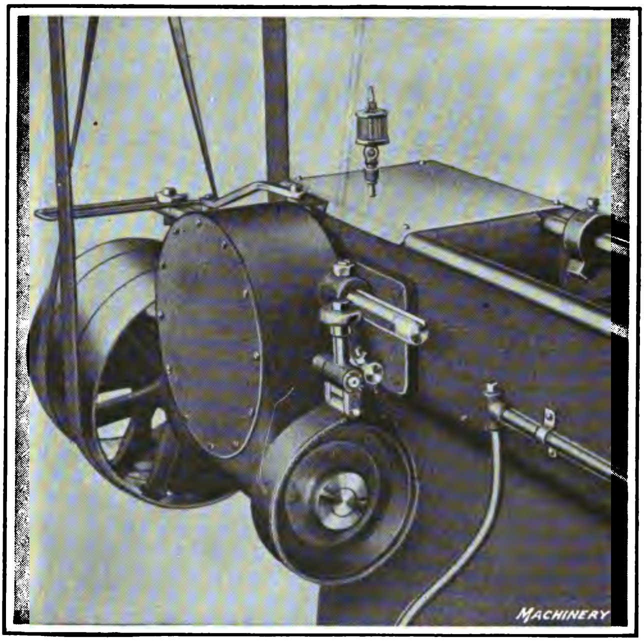

Fig. 7. View showing Tight and Loose Pulleys, Worm-wheel Housing, and Band Brake

dogs for the squared ends of the live spindles of rear axles and is being performed in an automobile plant. The dogs are held in position by the hollow jig A, which is bolted to the base of the press, the jig being slotted to conform to the teeth of the dog. As the ram of the press forces the broach through the hole, the dial shown registers the pressure in tons; the maximum allowable pressure is 30 tons. At R, in the lower right-hand corner of the illustration, there is shown one of the dogs after it has been broached.

Hydraulic Broaching. The Watson-Stillman Co., of Aldene, N. J., has made many presses for hydraulic broaching and uses several in its own shops for broaching operations on manufacturing work. These machines are all of the vertical type and have been found easier to handle with certain classes of work than the horizontal type. One

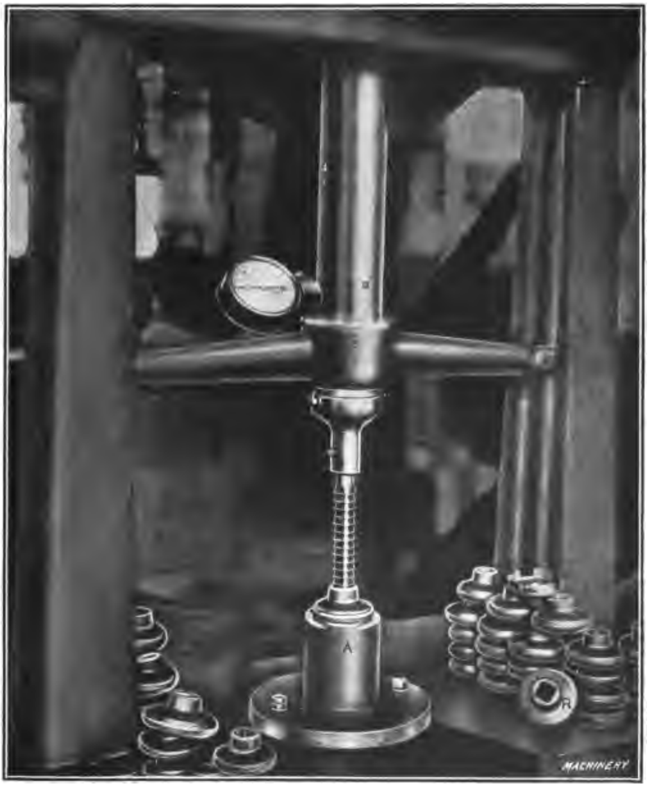

Fig. 8. Broaching Square Holes in a Vertical Hydraulic Press

of these presses is shown in Fig. 9. In Fig. 10 is shown a closer view of the press, that illustrates the facility with which the work may be handled. In the horizontal type of broaching machine the force required to drive the broach is applied through a driving screw, but with a hydraulic press it is applied through a ram driven by a pump.

An advantage claimed for hydraulic broaching is that short broaches may be used—from one-fourth to one-sixth of the length of broaches for horizontal use. On this account

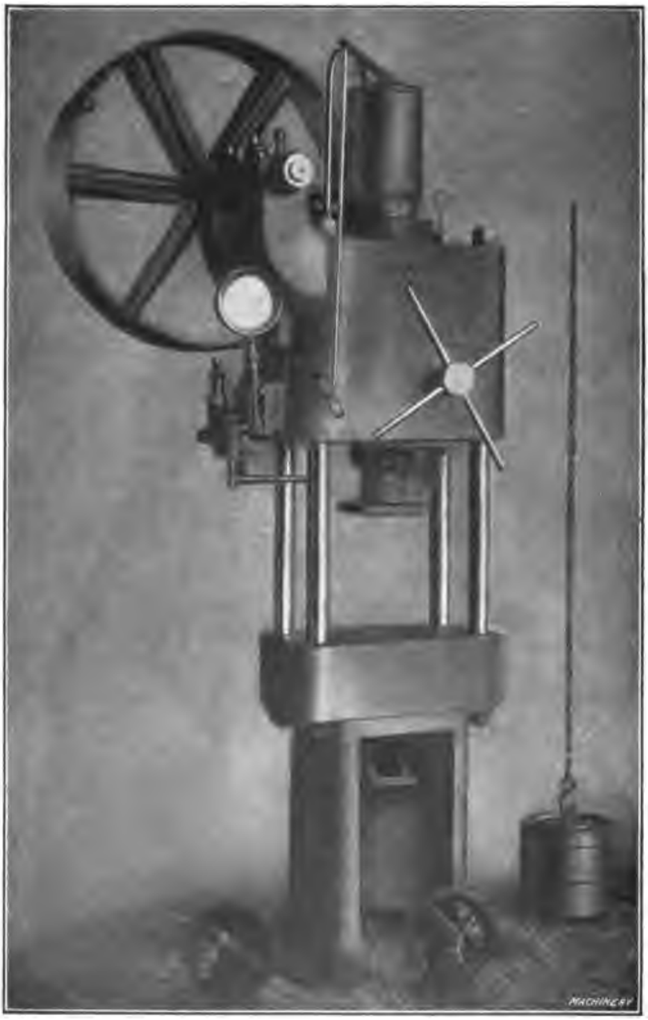

Fig. 9. Hydraulic Press used for Broaching

there is less danger of breakage in hardening or in use; the steel is under compression while in use, rather than under tension. When the work will permit it, the broaches

are driven clear through the hole and dropped out on the under side. In Fig. 11 there appears a set of four broaches for finishing a hole for a square shaft. The economy of using short broaches is apparent when it is stated that when

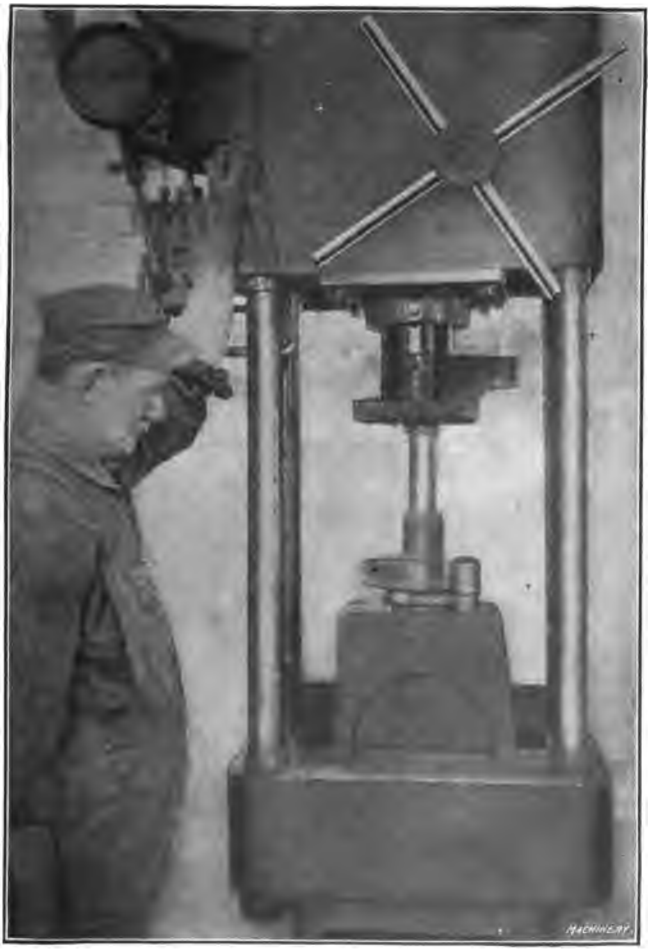

Fig. 10. Planish-broaching in a Hydraulic Press

the full-sized broach wears small it may be ground down to the next smaller size, and so on until the size of the last broach in the set is reached. Therefore it is necessary to replace only one broach each time the entire set is normally worn out.

An idea of the amount of metal removed in broaching with vertical or "push" broaches, as they are sometimes called, may be obtained from the table of sizes given in inches for the four broaches, *A, B, C* and *D* shown in Fig. 11.

	Broach A	Broach B	Broach C	Broach D
Start	1.075	1.100	1.125	1.145
Finish	1.105	1.130	1.155	1.155

From these figures it will be seen that each of the broaches removes practically 0.030 inch of metal, except the

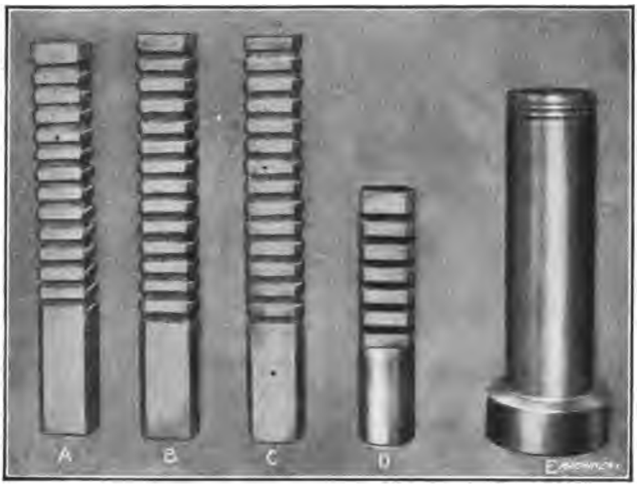

Fig. 11. A Set of Push-broaches

last broach, which has only 0.010 inch to take off to finish the work, and is therefore more in the nature of a smoothing broach.

The broaching operation illustrated in Fig. 10 shows the planish-broaching of a hole that has been previously drilled and reamed in the casting shown on the bed of the machine. The broach removes no metal, but planishes the stock on the surface of the hole, leaving it to size. This is practically an expanding operation, the hole being enlarged slightly as the metal is compressed; and, moreover, because the metal is compressed, the finish is much better and the wearing surface of the hole much harder.

The broach for this operation is shown at *E* in Fig. 11, and in Fig. 12 the details of the broaching end are given. The broach has four different sizes as shown. The reamed hole is 0.003 inch under size and the entering part of the broach is made just to size. The corners, however, are well rounded so that the broach will start without difficulty. The first raised rib on the broach end is made 0.002 inch over size. The next rib is left 0.003 inch over size, and the body of the broach is made 0.001 inch under size. The object of this broach is to planish the metal out to a size enough larger than the finished size to allow for the "spring-back" of the metal. The amount of "spring-back" depends, of course, upon the thickness of the wall and the character of the metal.

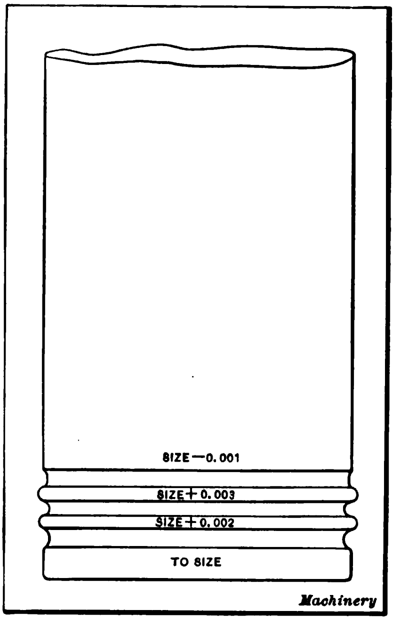

Fig. 12. Dimensions of the Planish Broach

In hydraulic broaching the amount of pressure that is being applied to the broach at all times is shown by the hydraulic gage. This is important as it tells the exact time at which an overload is being put on the broach and, the safety point of the broach being noted, it is easy to keep on the safe side. Any range of speed may be secured in hydraulic broaching, and this speed is only limited by the capacity of the broaching tool for doing the work. Less floor space is required for hydraulic broaching machines than for the horizontal type of broaching machine. The horizontal broaching machine is a single-purpose machine tool, in that it can only be used for broaching, but the hydraulic press, in addition to being used for broaching,

may be used for forcing on arbors, forcing gears on and off shafts, straightening, and for various other machine shop jobs requiring pressure.

Using Adjustable Broach in a Hydraulic Press. In an article published in MACHINERY by Jack Homewood, a description was given of the method of machining the shell of

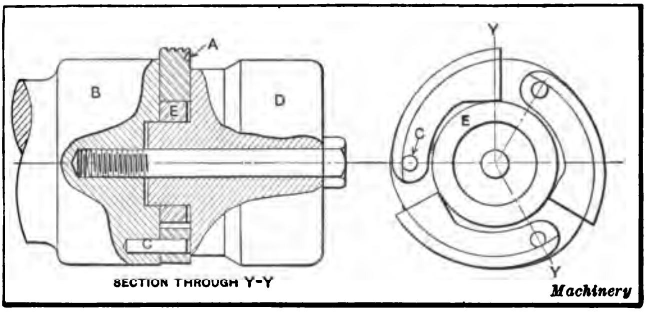

Fig. 13. Adjustable Broach used in making Shell Chuck

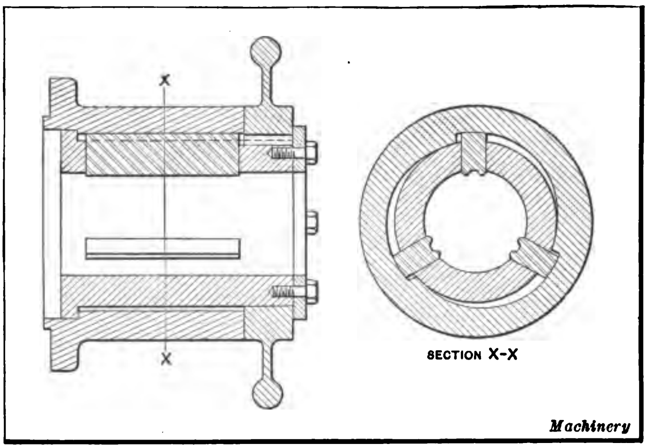

Fig. 14. Shell Chuck to be made

the chuck shown in Fig. 14 when a slotter or other machine suitable for quick production work of this class was not available. In this case, an adjustable broach, shown in Fig. 13, was used in a hydraulic press with very satisfactory results. There was a slight breaking away of the iron as the broach was almost through the work, but this was

cleaned away by counterboring. The body of this chuck has three internal cam surfaces, as shown in section *X-X* Fig. 14.

The broaching cutter is made of tool steel and was first turned up into a ring as shown in Fig. 15, the outside diameter of which was enough larger than the body of the holder to produce a cam surface of the proper depth and to leave enough of the concentric land to act as a guide for the steel jaw retaining sleeve. The shape of the three cutters *A* and the holes were then laid out as shown. After these cutters were cut out they were hardened and drawn to a straw color; as they retained their true shape, grinding was unnecessary. They were then set on the body *B*, Fig. 13. The pins *C* that hold the cutters are so located that the broach will form the proper cam surface when the cutters are in the expanded position. The body *B* is counterbored to receive the boss on the pilot *D*, which is relieved to make chip room under the cutting edge; provision is also made for the chips to drop through out of the way, as any clogging will tear the work, and the chances are that the broach would break. Four rings *E* were also made, the inside diameter being such that they fit on the pilot boss, and the outside diameters varying by 1/16 inch. The smallest ring is used first; in this operation, the broach removes 1/32 inch of the metal. This ring is then replaced by the next larger and so on until the four have been used. To be on the safe side, the last setting is put through three times, the broach being turned 120 degrees each time. A good finish, as well as sufficient accuracy, is thereby obtained. For a half dozen or more chucks, this method will be found economical.

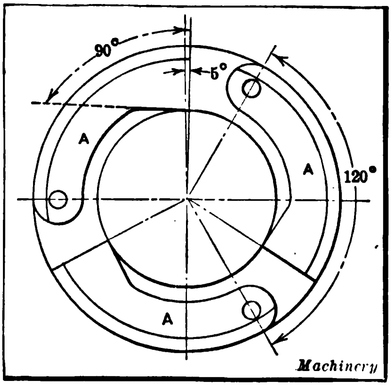

Fig. 15. Method of laying out Broaches

CHAPTER III

BROACHES AND BROACH MAKING

A NUMBER of typical broaches and the operations for which they are intended are shown in Fig. 1. Broach *A* produces a round-cornered, square hole. Prior to broaching square holes, it is usually the practice to drill a round hole having a diameter *d* somewhat larger than the width of the square. Hence the sides are not completely finished, but this unfinished part is not objectionable in most cases. In fact, this clearance space is an advantage during the broaching operation in that it serves as a channel for the broaching lubricant; moreover, the broach has less metal to remove. Broach *B* is for finishing round holes. Broaching is superior to reaming for some classes of work, because the broach will hold its size for a much longer period, thus insuring greater accuracy, and more economical results are obtained on certain classes of work.

Broaches *C* and *D* are for cutting single and double keyways, respectively. The former is of rectangular section and, when in use, slides through a guiding bushing which is inserted in the hole. Broach *E* is for forming four integral splines in a hub. The broach at *F* is for producing hexagonal holes. Rectangular holes are finished by broach *G*. The teeth on the sides of this broach are inclined in opposite directions, which has the following advantages: The broach is stronger than it would be if the teeth were opposite and parallel to each other; thin work cannot drop between the inclined teeth, as it tends to do when the teeth are not inclined, because at least two teeth are always cutting; the inclination in opposite directions neutralizes the lateral thrust. The teeth on the edges are staggered, the teeth on one side being midway between the teeth on the other edge, as shown by the dotted line.

A double-cut broach is shown at *H*. This type is for finishing, simultaneously, both sides *f* of a slot, and for similar work. Broach *I* is the style used for forming the teeth in internal gears. It is practically a series of gear-shaped cutters, the outside diameters of which gradually increase toward the finishing end of the broach. Broach *J* is for round holes but differs from style *B* in that it has a

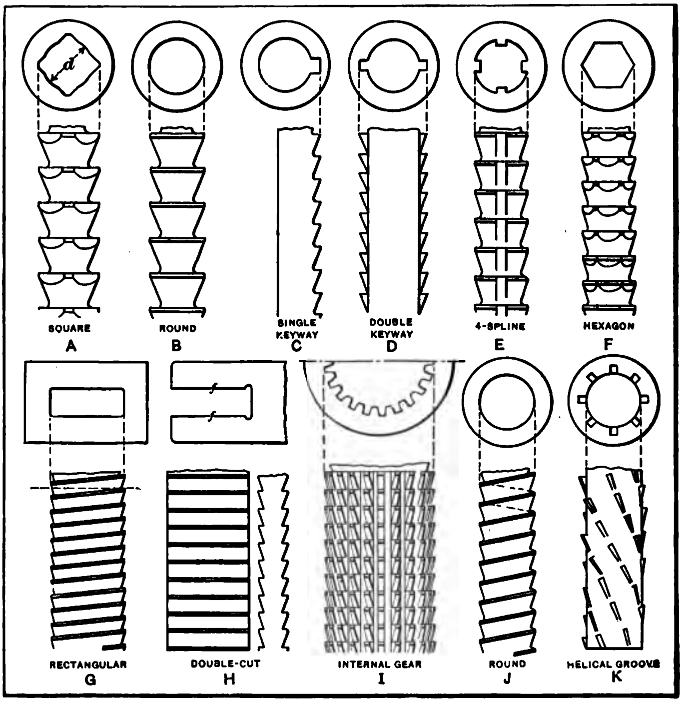

Fig. 1. Types of Broaches and Examples of Broached Work

continuous helical cutting edge. Some prefer this form because it gives a shearing cut. Broach *K* is for cutting a series of helical grooves in a hub or bushing. The work rests against a special rotating support, and revolves to form the helical grooves, as the broach is pulled through.

In addition to the typical broaches shown in this illustration, many special designs are now in use for performing more complex operations. Two surfaces on opposite sides

of a casting or forging are sometimes machined simultaneously by twin broaches and, in other cases, three or four broaches are drawn through a part at the same time, for finishing as many duplicate holes or surfaces. Special work-holding and broach-guiding fixtures are commonly used for multiple broaching. In Chapter IV a variety of special broaching operations are described and illustrated and indicate in a general way the possibilities of the broaching process.

Designing Broaches. In the manufacture of broaches, there are many questions which require serious consideration if the success of the finished tools is to be insured, and, owing to the fact that each type of work has to be investigated on its own merits, it is difficult to give any definite rules that will govern the design and manufacture of these tools. Formulas for determining broach dimensions cannot be followed very closely but must be taken as a guide in conjunction with the lessons taught by experience. The material of which the parts to be broached are made, as well as the shape or design of the part and the amount of material to be removed, all have their influence on the proportions of the broaches. The amount of metal which each tooth of the broach is called upon to remove also influences the volume of chip space required, and this, in turn, governs to some extent the distance between the broach teeth, or the pitch, as well as the depth of the chip space.

Some experienced manufacturers, after expensive experiments and costly failures, have come to the conclusion that the pitch of the broach teeth is one of the most vital points, as when this dimension is correctly determined, the other proportions and details can be arranged to suit. The pitch should not be made too fine, but as large as convenient under the circumstances, without causing weakness in the core of the broach. It has often been thought that a broach with finely pitched teeth, each tooth removing a comparatively small amount of metal, stood a better chance, but this is not by any means the case.

Special Rules for Pitch of Broach Teeth. In attempting to broach a hole of any given length, it is obviously a good

point to have at least two teeth in an actual cutting position at all times, until the broach has finished cutting; but with certain work, the length through the broached portion is the matter which must be considered first. In some instances, as, for example, a thin disk, it is not possible to arrange for more than one tooth to be passing through the broached portion at all times, and then it is highly advisable to arrange the parts in a row so that the whole depth of the hole to be broached is three times the pitch of the broach teeth. Care should be exercised in clamping the

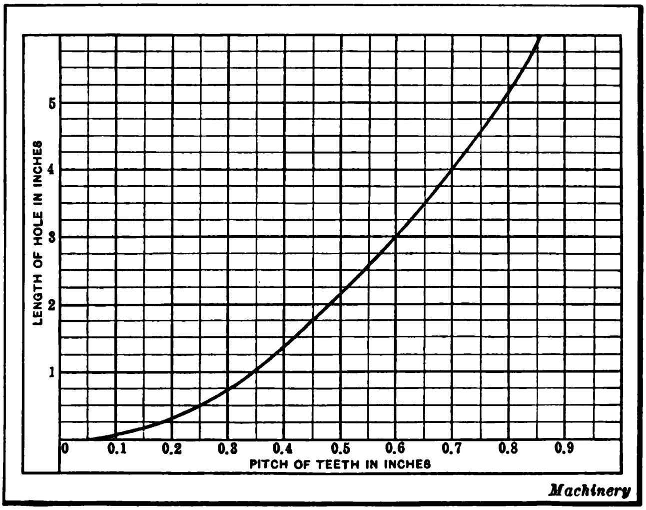

Fig. 2. Chart showing Pitch of Broach Teeth

disks, so that they are all kept absolutely in line, as one falling out of place would cause fracture of the broach or destruction of the part.

Should the article be of a peculiar design which will not allow several to be broached at a time, then the broach must be supported and kept in its correct position by a guide hole which bears on a part of the broach that has no cutting edges, and which, in turn, is definitely located in relation to the article being broached. Work in connection with the automobile and allied industries, however, has generally a reasonable length of the broached portion, and

in such cases the chart illustrated in Fig. 2 will be found to give good results in determining the pitch of the teeth. In order to avoid the manufacture of unnecessary tools, one size of broach is frequently used for several different parts having varying lengths of hole. In such cases the distance through the shortest hole should be used in determining the pitch of the broach teeth.

The results given in the chart enable a reasonable pitch to be determined. Very fine pitches are avoided as much as possible, as the power required to pull a fine-pitched broach through the work frequently causes the end of the broach to be pulled off, owing to the cutting portion becoming choked in the hole.

Differential Pitching of Teeth. The advantages of spacing the teeth irregularly (to a limited degree) do not appear to be fully appreciated, or if appreciated, do not appear to be considered as sufficiently great to justify the slight additional trouble necessary in differential spacing. There is no doubt, however, that, particularly when broaching comparatively hard or tough material, the additional time occupied in the manufacture of the broach is fully compensated for. The object of this modification in design is to produce a better finish on the work; at the same time the working life of the broach is somewhat lengthened. The broaching operation can by no means be regarded as a smooth operation, like the taking of a fine cut on a lathe, but there is always a certain amount of chatter, and in the case of a broach having teeth evenly spaced along its whole length, any one tooth has a tendency to produce the same irregularities as the preceding tooth, and consequently the trouble is to some degree accentuated. When teeth of slightly varying pitch are used, any given tooth tends to remove irregularities left by the previous tooth.

There is no fixed rule for determining the most suitable amount of variation from standard, but probably an increase of 0.004 inch for each of four spaces, making a total of 0.016 inch for the last tooth, will be found generally satisfactory; the next following space will be made standard, and then the increase started again. In the case of a

broach for which a tooth pitch of 5/8 inch has been decided upon, the spacing would be as follows:

	Inch		Inch
First space	0.625	Fifth space	0.641
Second space	0.629	Sixth space	0.625
Third space	0.633	Seventh space	0.629
Fourth space	0.637	Eighth space	0.633

and the sequence repeated. In some instances more than, and sometimes less than, the increment suggested above is used; spline broaches, for automobile sliding gear holes, are mostly made with equally spaced teeth, but experience has proved the value of the idea, particularly in the case of tools where it is necessary to remove metal around the greater portion of the cross-section of the broach.

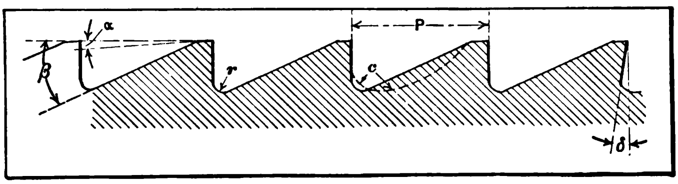

Fig. 3. Diagram Illustrating Pitch, Clearance, Rake, and Filleting

Formula for Pitch of Broach Teeth. As a general rule, the pitch P (see Fig. 3) should increase as the length of the hole increases to provide sufficient space between the teeth for the chips. The pitch of the teeth for broaching under *average* conditions can be determined by the following formula, in which P = pitch of teeth and L = length of hole to be broached:

$$P = \sqrt{L} \times 0.35$$

This formula expressed as a rule would be:

Rule: The pitch of the teeth equals the square root of the length of the hole multiplied by the constant 0.35.

For example, if a broach is required for a square hole 3 inches long, the pitch of the teeth would equal $\sqrt{3} \times 0.35 =$ 0.6 inch, approximately.

Of course a given pitch will cover quite a range of lengths, the maximum being the length in which the chip space will

be completely filled. The constant given in the preceding formula may be as low as 0.3 for some broaches and as high as 0.4 for others, although the pitch obtained with the value 0.35 corresponds to average practice. When a broach is quite large in diameter, thus permitting deep chip spaces in front of the teeth, the pitch might be decreased in order to reduce the total length of the broach. On the other hand, if the work is very hard and tough, a coarser pitch might be advisable in order to reduce the power required to force the broach through the hole.

If the pitch is too fine in proportion to the size of the broach, there may be difficulty in hardening, owing to the fact that the fine teeth will cool much more rapidly than the broach body, thus producing severe strains which tend to crack the teeth, especially at the corners. And, as previously mentioned, if the teeth are too closely spaced, so much power may be required for drawing the broach through the work that there is danger of pulling the broach apart. In general, the pitch should be as coarse as possible without weakening the broach too much, but at least *two teeth should be in contact* when broaching work of minimum length.

Depth of Cut per Tooth. The amount of metal that the successive teeth of a broach should remove, or the increase in size per tooth, depends largely upon the hardness or toughness of the material to be broached. The size of the hole in proportion to its length also affects the depth of cut, so that it is impossible to give more than a general idea of the increase in size per tooth. Medium-sized broaches for round or square holes usually have an increase of from 0.001 to 0.003 inch per tooth for broaching steel, and approximately double these amounts for soft cast iron or brass. Large broaches up to 2 or 3 inches may have an increase of from 0.005 to 0.010 inch per tooth. Obviously, the depth of cut is governed almost entirely by the nature of the work. For example, a small broach for use on brass or other soft material might have a larger increase per tooth than a much larger broach for cutting steel. If the amount of metal to be removed is comparatively small and

the broach is used principally for finishing, the increase per tooth may not be over 0.001 inch even for large broaches.

The diagrams *A* and *B*, Fig. 4, show a common method of broaching square holes in the hubs of automobile transmission gears, etc. Prior to broaching, a hole is drilled slightly larger in diameter than the square width. The first tooth on the broach is rounded and cuts a long circular chip, as indicated at *a*, and the following teeth form the square corners by removing successive chips (as shown by the dotted lines) until the square is finished as at *B*. As will be seen, the first tooth has the widest cut, the chip width *a* greatly decreasing toward the finishing end of the broach.

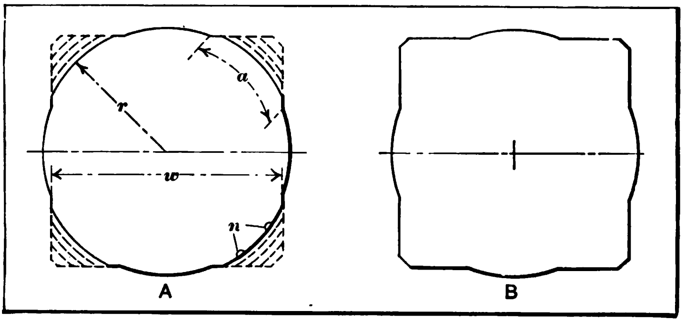

Fig. 4. Diagram Illustrating Distribution of Tooth Cuts in broaching a Square Hole

Hence, if this hole were finished with a single broach, it would be advisable to vary the sizes of the teeth so that the depth of cut gradually increases as width *a* decreases.

It is good practice to nick some of the wide teeth as indicated at *n*, in order to break up the chips, as a broad curved chip does not bend or curl easily. In case two or more broaches are required, the first broach of the set may have a uniform variation in the radii *r* of different teeth, but the depth of cut should be less than for the following broaches which remove comparatively narrow chips from the corners of the square. Several end teeth, especially on the last broach of a set, are made to the finish size. This feature, which is common to broaches in general, aids the

broach in retaining its size and tends to produce a more accurately finished hole.

Testing Uniformity of Teeth. When testing a broach to determine if all the teeth cut equally, first use a test piece not longer than twice the pitch of the teeth. Pull the broach through and note the amount of chips removed by each tooth; then "stone down" the high teeth and test by drawing through a longer piece, and, finally, through the full length required. If a broach is warped much, or is otherwise inaccurate, some teeth may take such deep cuts that the broach would break if an attempt were made to pull it through a long hole on the first trial.

Clearance Angles for Broach Teeth. The clearance angle *a* (Fig. 3) for the teeth of broaches is usually very small, and some broaches are made with practically no clearance. Ordinarily there should be a clearance angle varying from 1 to 3 degrees, 2 degrees being a fair average. A common method of providing the necessary clearance is as follows: All the lands of the hardened broach are first ground parallel and then they are "backed off" slightly by means of an oilstone. Just back of the narrow land (which may not be over 1/32 inch wide), there is a clearance of 2 or 3 degrees, machined prior to hardening.

As previously stated the clearance space required for the chips depends upon the length of the hole and the depth of the cut. When the cut is light, and especially if the material to be broached is tough, thus making it necessary to use as strong a broach as possible, the clearance space should be proportionately small. The fillet at the base of each tooth should have as large a radius *r* (Fig. 3) as practicable and the grooves between the teeth should be smooth so that the chips will curl easily. A curved clearance space, similar to that indicated by the dotted line *c*, is superior to the straight slope, although not so easily machined. The front faces of the teeth are sometimes given a rake *s* of from 5 to 8 degrees so that the broach will cut more easily and require less pressure to force it through the holes.

Steel for Broaches. Three kinds of steel are used for making broaches; namely, alloy steel, carbon steel and, to

some extent, casehardened machine steel for short "push" broaches. Carbon-vanadium tool steel is especially adapted for broaches. This steel differs from the high-speed steels in which vanadium is also used in that it does not contain tungsten or chromium, but is simply a high-grade carbon steel containing a certain percentage of vanadium. The addition of vanadium to carbon steel imparts certain qualities, the most important of which are, first, the higher temperature to which the steel can be heated without coarsening the grain (thus permitting a greater range in temperature for hardening without spoiling the tool), and second, the tough core which makes the broach stronger and more durable than one made of regular high-carbon steel. The makers recommend hardening carbon-vanadium steel at a temperature varying from 1350 to 1425 degrees F., the temperature depending somewhat upon the size of the tool. The steel is then drawn to suit conditions, the drawing temperature generally being about 460 degrees F. This particular brand of steel will not harden in oil.

Regular carbon steel that is used for broaches should have from 1.00 to 1.10 per cent carbon. To prevent the steel from warping excessively, the broach should be annealed after the teeth have been roughed out. A successful method of hardening to prevent excessive warping is as follows: After machining the broach and before hardening, heat to a dark red and allow the broach to cool while lying on a flat plate, then heat to the hardening temperature and harden in the usual manner. This method, which is applicable to all tool steels, reduces warping to a minimum and is of especial value when hardening slender broaches.

Straightening Hardened Broaches. Broaches that have been warped by hardening can be straightened at the time the temper is drawn. Place the broach on two wooden blocks on the table of a drill press equipped with a lever feed, and insert a wooden block in the end of the drill press spindle. Heat the broach with a Bunsen burner until the hand can barely touch it; then apply pressure to the "high" side. Continue heating (as uniformly as possible) and bending until the broach is straight, but complete the

straightening operation before the broach has reached a temperature of about 350 degrees F., so that the drawing temperature will not be exceeded. With this method the heat required for straightening is also used for drawing the temper, the broach being removed and quenched as soon as the tempering temperature is reached. The temperature is judged by brightening some of the teeth throughout the length of the broach and watching the color-changes as the temperature increases.

Proportions of Broaches for Different Operations. The following examples of broaching taken from actual practice indicate, in a general way, the proportions of broaches for various operations:

Operation 1. Broaching 15/16-inch square holes in alloy steel gears having hubs 3 inches long. Broaches used: The first or No. 1 broach in the set of three has teeth which increase in diameter from the starting end 0.002 inch; the teeth on No. 2 broach increase 0.003 inch, and those on No. 3, 0.004 inch. The leading ends or shanks of the three broaches are 0.005 inch less in diameter than the 1-inch hole drilled prior to the broaching operation. The pitch of the teeth is ½ inch; the width of the lands, ⅛ inch; the last two teeth on broaches Nos. 1 and 2 are made the finished size; six teeth of the finished size are left on broach No. 3. When more than one broach is used, it is common practice to make the last tooth on one broach and the first tooth on the following broach of the same size.

Operation 2. Broaching a ⅝-inch square hole, 1½ inch long, in carbon steel. Broaches used: Set of three push broaches (for use under a press), 10¼ inches long; pitch of teeth, 5/16 inch; increase in size per tooth, 0.003 inch (0.0015 on each side). A 21/32-inch hole is drilled prior to broaching.

Operation 3. Broaching a 9/16-inch hexagon hole, ⅞ inch long, in high-grade carbon steel. Broaches used: Set of four push broaches, 6 inches long; pitch of teeth, ¼ inch; increase in size per tooth, 0.010 inch (0.005 on each side) for first six teeth (because of small corner cuts taken by leading teeth), and 0.003 inch for remaining eight teeth.

The last six teeth on broach No. 4 are made the same size.

Operation 4. Finishing babbitted or bronze bearings, $1\frac{1}{2}$ inch diameter, 3 inches long. Broaches used: Pitch of teeth, 7/16 inch; length of toothed section, 4 inches; increase in size per tooth, 0.001 inch; number of uniformly sized finishing teeth, 3; width of lands, 1/32 inch; size of pilot, 1.495 inch; length, $1\frac{3}{4}$ inch; size of plain cylindrical section following finishing teeth for producing hard and compact surface, 1.505 inch.

Operation 5. Broaching the teeth in machine steel internal gears of 3.3-inch pitch diameter; 20 diametral pitch, with teeth $\frac{1}{2}$ inch long. Broaches used: Pitch of teeth (distance between centers of successive rows), $\frac{3}{8}$ inch; increase in outside diameter for each annular row of teeth, 0.006 inch; number of rows of uniform diameter, last three.

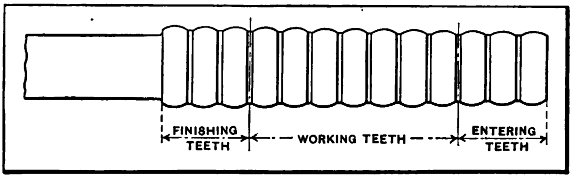

Fig. 5. Smooth-tooth Broach used for machining Bearings

This type of broach is illustrated at *I*, in Fig. 1, and is made as follows: After roughing out the blank, anneal the steel; then mill the teeth the same as if making a long gear; harden and grind the front faces of the teeth to produce sharp edges. The cutting ends of the teeth require little or no clearance.

Smooth-tooth or Planishing Broaches. Fig. 5 shows a planishing broach of somewhat different design from the one described in the preceding chapter. The teeth are rounded at the top instead of being finished to a cutting edge as in the ordinary type of broach. These teeth are highly polished, as experience has shown that the higher the polish, the better the results obtained with the tool. It will be seen that the first few teeth are small enough to enter the hole which is to be broached, the intermediate teeth are

of slightly larger diameter, and the last three teeth are of the size to which it is desired to finish the work.

This tool is used for broaching bearings and for operations on other classes of work where the metal is relatively soft, the tool compressing the metal, and thus giving it a surface hardness. This is of particular value in the case of bearings, on which class of work this broach has found wide application. The amount of metal displaced by the broaching operation is about the same as that removed by reaming, depending largely on the kind of metal and the construction of the broach. Although the tool is primarily intended for operations on babbitt and white bearing metal and brass, it has been used satisfactorily for producing glazed surfaces on cast-iron bearings.

The distance from center-to-center of the teeth depends somewhat on the length of the work which is to be broached. It is desirable to have at least six or eight teeth working at all times. This broach is usually made as shown in the illustration and is pushed through the work instead of being pulled in the ordinary way. An arbor or screw press may be used for this purpose and it is generally advisable to apply lubricant to the broach while in operation.

The noteworthy feature of the operation of a broach of this type, as compared with an ordinary smooth plug, lies in the reduction of friction. It will be evident that the teeth of this broach are fully as efficient as a plug for handling the class of work for which the tool is intended. At the same time, the area of the tool in contact with the work is greatly reduced, with a corresponding reduction of friction and the amount of power required to drive the tool. The provision of teeth also makes it possible to apply lubricant to the work more readily than could be done if an ordinary plug were used.

Sizing Round Holes with Planishing Broach. Fig. 6 shows how a broaching machine and planishing broach were used for sizing holes in hard phosphor-bronze bushings. This material, as any mechanic who has had any experience with it knows, is difficult to finish-ream. It is tough, elastic and slippery, and the less there is to ream the more difficult

becomes the operation. Instead of reaming, the holes are enlarged slightly by pulling a smooth-tooth broach through in a regular broaching machine. It will at once be seen that the operation is that of compressing the metal in the sides of the hole until it has been enlarged to the finished size. Each of the rounded rings or beads on the broach is a little larger than its predecessor, thus gradually compressing the metal the desired amount. The finished hole springs back to a diameter a few thousandths inch less than the diameter of the largest ring on the tool, so that the size of the latter has to be determined by experiment. This allowance varies slightly also, as may be imagined, with the thickness of the wall of metal being pressed. In such a part as that shown,

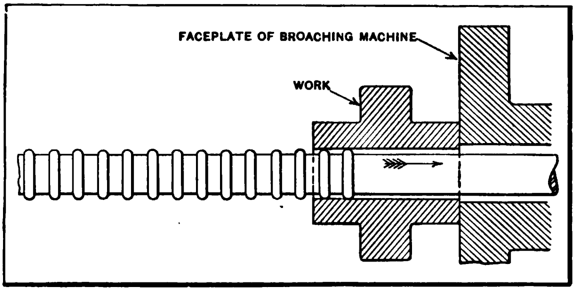

Fig. 6. Method of sizing Phosphor-bronze in the Broaching Machine by Compression

for instance, after drawing through the sizing tool in the broaching machine, it will be found that the hole will be somewhat larger in the large diameter of the work than in the hubs. It has been found that this difference in size can be practically avoided by passing the sizing tool through the work three or four times. The operation is a rapid one as compared with reaming.

Keyway Broaches with Inserted Teeth. In Fig. 7 are shown two designs of inserted-tooth broaches which may be employed for broaching keyways in thin sleeves such as shown in the upper right-hand corner of the illustration. The broaches are of the push-through type; consequently the sleeves are held in a vertical position in a suitable fixture so as to allow the broaching tools to fall through the work

after the keyways have been cut. The fixture is equipped with a hardened and ground steel bushing in which the body of the sleeve fits and against which its shoulder rests.

The tool shown at *A* in the illustration has two strips of cutting teeth *E* which are set in grooves milled in the shank and held in position by cutting a shallow groove *X* along one side of the strips and then peening the metal of the shank into these grooves as shown in the enlarged sectional view. A small collar *F* is pinned to the shank as a stop for these strips, the arrangement being entirely suitable for the small work for which broaches of this type are intended. One objectionable feature of the tool is that the strips of

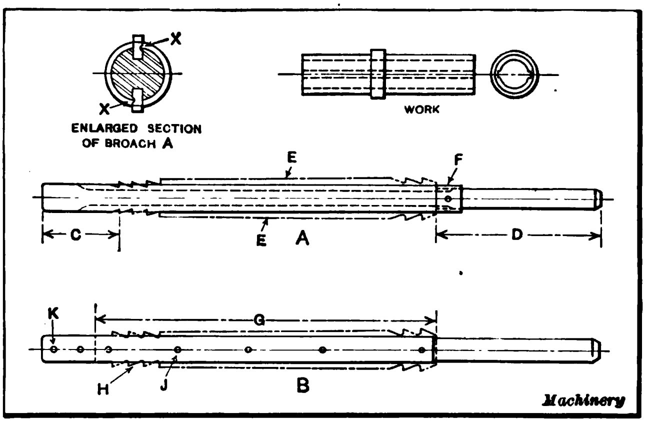

Fig. 7. Inserted-tooth Broaches for Light Work

teeth cannot be removed without ruining the shank. The length *C* of the shank acts as a pilot in the bushing and the opposite end *D* is reduced in diameter so that it will readily fall through the work at the completion of the operation.

The broach shown at *B* contains but one set-in strip *H*, which fits into a slot cut through the shank and which is held in place by means of small pins *J*. This strip, as will be seen, has two sets of cutting teeth. The slot in which this strip fits is cut from the pilot end of the body to a depth suitable for the length *G* of the strip, the end of the slot *K* being closed with a filling strip, which is held in the slot by means of two small pins. This construction enables the

cutting strip to be replaced when necessary by simply driving out the pins and substituting new strips of teeth. The latter construction is an economical method of making broaches of this type which, it should be mentioned, are intended to be used on an arbor press and for light work only.

Pull-bushing for Broaches. The broaches used on regular horizontal broaching machines are usually secured to the pull-bushing by means of a key passing through the bushing and broach. This connection frequently fails, the pull-bushing giving way as shown by the lower view in Fig. 8, or the end of the broach breaks off. The trouble can be over-

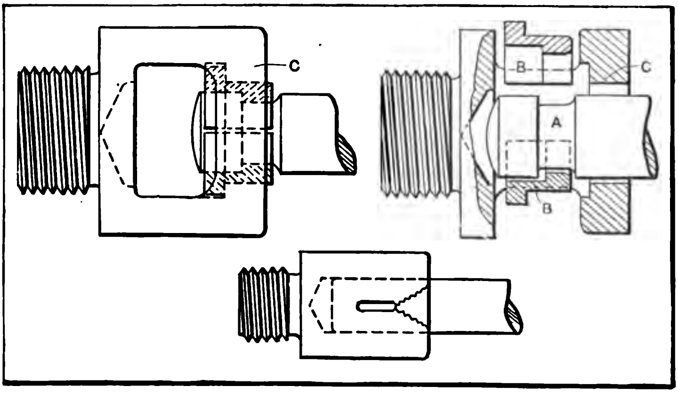

Fig. 8. Design of Pull-bushing for Broaching Machines

come by using a pull-bushing of the type illustrated by the two upper views.

The end of the broach is reduced in diameter as shown at *A*, leaving a shoulder; half-bushings are turned to suit the bore *C* of the pull-bushing and are made to fit freely the end of the broach. The pull-bushing has a slotted hole, wide enough for the insertion of these split bushings.

In use, the broach end is inserted through the hole in the pull-bushing, the half-bushings are placed on the neck and are then drawn back into the hole, as shown by the view to the left. By making the bore large enough when designing a pull-bushing of this form, it is quite a simple matter to arrange for one bushing to cover a large range of

broaches, and in each case retain the greatest possible strength in the broach. Split bushings are made to suit each size of broach. The width of the shoulders in the split bushings should be such that they will break before the strain is great enough to break either the main pull-bushing or the end of the broach.

Suggestions for Overcoming Broaching Troubles. In setting up a broaching machine for cutting any shape of hole, care should be taken to ascertain that the center of the pull bushing or broach holder is in line with the center of the faceplate hole. If the broach holder is slightly above or below the proper position, it will cock the work out of place, and even if the broach is not broken, the hole cut by it will not be perpendicular to the faces of the work. Should it happen that trouble is experienced through tearing the material, or that there is a tendency for the metal to break out around the end of the hole adjacent to the faceplate of the broaching machine, either of the following remedies may be applied; namely, the metal may be heat-treated to bring it to a scleroscope hardness of from 30 to 35. In some cases this trouble can be eliminated by grinding a 10- to 15-degree rake on the face of the broach teeth or by backing the metal up with a 1/4-inch collar between the work and faceplate, so that this collar will be broached out to the shape of the finished hole. For broaching bronze or other non-ferrous metals, a straightfaced tooth with about 1/2-degree top clearance will usually be found to give the most satisfactory results. In broaching square or hexagonal holes, if the broach tends to drift to one side owing to lack of provision for grinding it, two or three very light lengthwise rubs of an oilstone on the side of the broach teeth which cut fastest, will often remove the cause of trouble. As in other methods of machining, accidents are bound to occur in the performance of broaching operations; and if one or two teeth of a broach are broken, stoning or restepping the following two or three teeth will put the tool in good condition for subsequent use. In shops where broaching machines have been recently adopted and only a limited amount of experience has been obtained in their use, careful atten-

tion paid to the preceding recommendations will often be the means of substantially improving the rates of production and the quality of workmanship attained.

Graphical Method of Designing Broaches. In designing pull-broaches, it is desirable to proportion the sizes of the teeth so that each tooth will remove an equal amount of stock from the part being broached and prevent the broach from being subjected to irregular stresses. This usually means that the depth of cut taken by each successive tooth should not increase by a constant amount over that of the preceding tooth, but should increase by a varying amount. For instance, when a square hole is broached from a round one, the width of each successive cut decreases, and in order to remove the same quantity of stock, the diameter or distance across the corners of each successive tooth must be increased in proportion. Thus if the first teeth of a broach take cuts 0.001 inch deep, the last teeth might be required to take cuts 0.010 inch deep in order to remove a like quantity of stock.

Figs. 9 and 10 illustrate a graphical method of determining the diameter or size of any tooth of any type of broach after the total amount of stock to be removed has been determined. This method was described in MACHINERY by George C. Hanneman. The depth of a cut that any tooth can take, of course, depends upon the hardness and toughness of the material from which the work is made. In order to show the application of the method, assume that it is desired to find the dimensions of the teeth of a pull-broach which is to cut a 0.750-inch square hole from a hole 0.750 inch in diameter. First draw these holes to a large scale of about 10 to 1, as sown in Fig. 9, in which the dotted square represents the hole to be broached and the full circle represents the original round hole. Next draw line *OP* from one corner of the square to center *O*. Let *h* equal the distance across the corners of the final hole minus the diameter of the original hole; then $h/2$ equals the height of the metal to be removed from one corner, when measured along line *OP*. Next divide $h/2$ into ten equal spaces by arcs *B, C, D,* etc., struck from center *O*. The area of the space between arcs

A and *B* is obviously considerably larger than the area between arcs *B* and *C*, because the nearer the space is to the corner of the square, the smaller the area naturally becomes. This proves that if the successive teeth on a broach took cuts of the same depth, the amount of metal removed by each successive tooth would be considerably smaller than the amount removed by the preceding tooth. In fact, the first 10 per cent of the teeth would remove about 25 per cent of the stock which is not, of course, desirable. The next step is

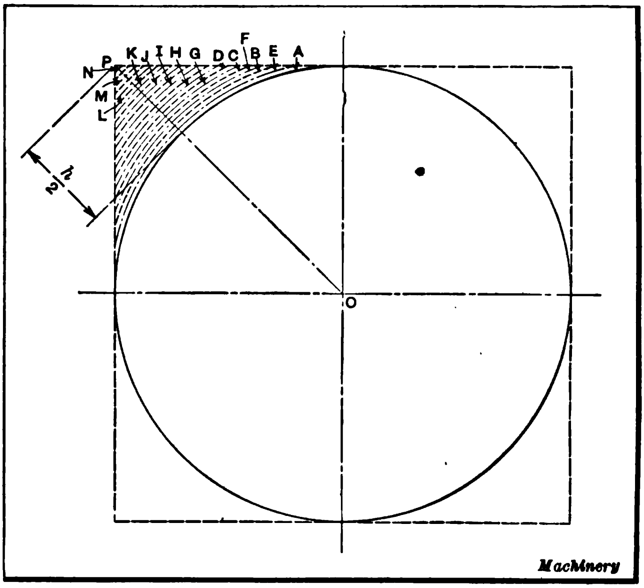

Fig. 9. Method of determining Size of Broach Teeth

to draw arcs *E*, *F*, *G*, etc., midway between the arcs previously drawn. The lengths of the newly constructed arcs will be in the same proportion as the areas between the arcs *A*, *B*, *C*, etc.

Diagram for Finding Size of Teeth of Square Broach. Referring to Fig. 10, next draw a horizontal line *XY*, on which lay out spaces equal to one-half the lengths of the arcs *E*, *F*, *G*, etc., Fig. 9, to the same scale as the diagram in that illustration was constructed, and erect a vertical line between each space. At the left-hand end of line *XY*,

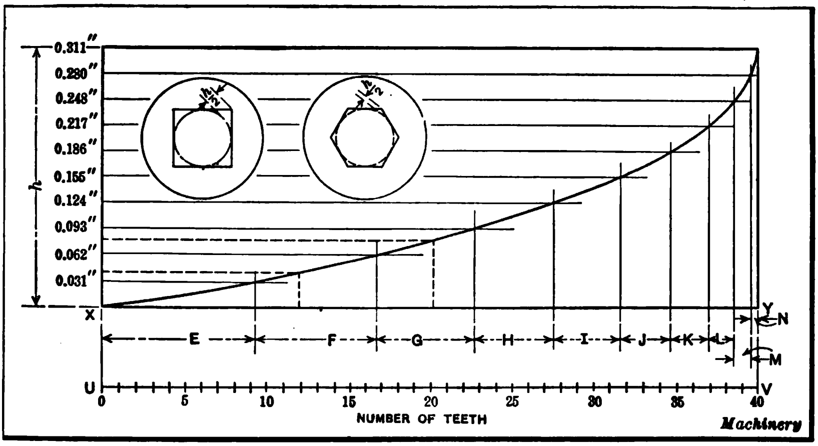

Fig. 10. Developed Diagram by Means of which Broach Teeth Sizes are determined

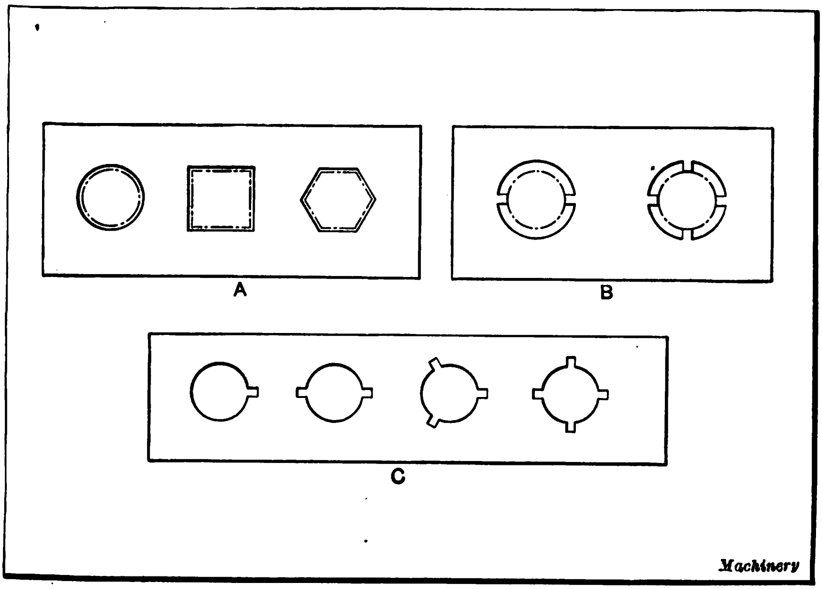

Fig. 11. (A) and (B) Holes for which the Developed Broach Curve will be nearly a Straight Line. (C) Holes for which a True Straight Line will be developed

erect a vertical line equal in length to the value h when laid out to a convenient scale, also of about 10 to 1. In the example given, h can be found by multiplying the diameter of the round hole by 0.414; thus $h = 0.414 \times 0.750 = 0.3105$.

Therefore, line h should be drawn $10 \times 0.3105 = 3.105$ inches long. Next divide this line into ten equal spaces and erect horizontal lines to the right until they intersect with the vertical lines previously drawn, after which construct a curved line through each point of intersection. The value of each horizontal line should be marked at the left end. The tooth line UV should then be drawn the same length as the diagram and should be equally divided according to the number of teeth that the broach is to have. In the example given, assuming that the broach is to have forty teeth, this line would be spaced as illustrated.

The method of finding the correct size of any tooth of a broach is as follows: Locate the point on the tooth line corresponding to the tooth in question, then from a point on the base line of the diagram directly above the point of the tooth line, erect a vertical line until it intersects with the curve, then from this intersection project a line to line h, and add the value obtained there to the diameter of the original hole. Thus in the example given, the amount to be added to the diameter of the round hole to find the diameter of the twelfth tooth is approximately 0.043 inch so that this dimension would be $0.750 + 0.043 = 0.793$ inch. Similarly, the diameter of the twentieth tooth would equal $0.750 + 0.080 = 0.830$ inch. An examination of the diagram will show that if a broach is designed in this manner, 25 per cent of the stock to be removed will be removed by the first 25 per cent of the teeth, instead of by the first 10 per cent as in the case previously referred to.

Proportioning Teeth of Other Styles of Broaches. Curves similar to the one shown in Fig. 10 will be developed for all broaches of a square or hexagonal shape such as shown within the circles in the diagram. Fig. 12 shows the curve that will be developed for a square broach with rounded corners. In this instance, $h/2$ was divided into six equal spaces, so the chart was constructed accordingly. Fig. 13 shows the curve for a square broach also having rounded corners, but with the original round hole somewhat larger in diameter than the width of the final square hole. In this case $h/2$ was divided into eight equal spaces.

In cases where the hole broached is simply enlarged without altering the shape, as in the examples shown at *A*, Fig. 11, the depth of the cut decreases slightly with each successive tooth. The curve developed for broaches of this type is almost a straight line, the same being true for broaches used on holes of the type shown at *B*. However,

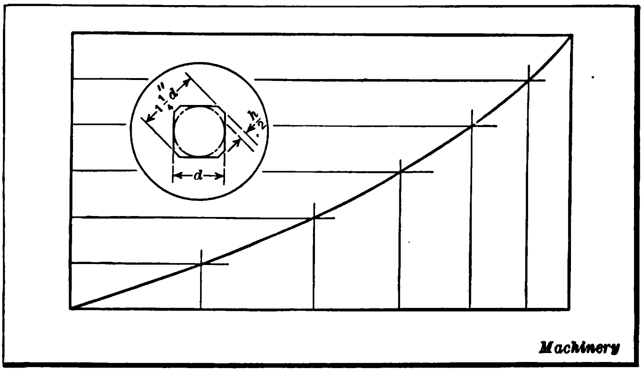

Fig. 12. Type of Curve that is developed for finding Sizes of Teeth for Square Broaches having Rounded Corners

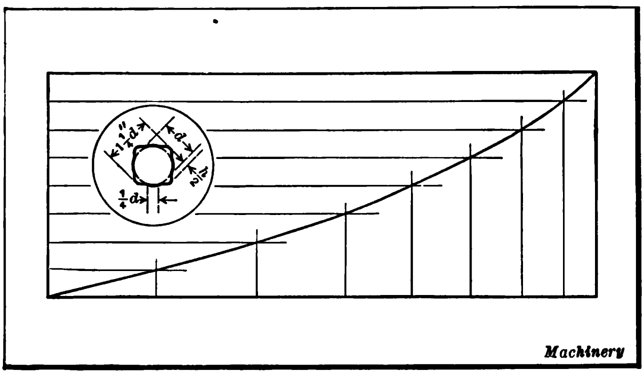

Fig. 13. Curve for Square Broaches with Rounded Corners when Diameter of Hole is Larger than Width of Final Square

for accurate work and especially when the work is very thick in comparison with the diameter of the hole, a curve should be developed in connection with the design of the broach. When keyways or splines are broached in the hole, as shown at *C*, a true straight line will be developed on the diagram instead of a curved line.

The method described can also be adapted to the design of push-broaches, but then the diagram should be so constructed that the first teeth do not remove as much stock as the last teeth. This is because the length of the broach in compression, or the distance between the engaged teeth and the end of the broach attached to the machine, decreases as the broach is forced through the hole, and as this distance becomes smaller, greater loads can be carried by the broach with less danger of flexure. This correction can be readily made by irregularly spacing arcs *B, C, D,* etc., in Fig. 9, making the spaces nearest to the center narrower than the others. By a thorough understanding of the method described, a designer is enabled to proportion a broach properly for machining holes of any shape. As broaches are comparatively expensive, it is well to design them so that equal stresses are placed on each tooth, thus increasing their life.

CHAPTER IV

EXAMPLES OF BROACHING PRACTICE

A GENERAL idea of the adaptability of modern broaching machines when equipped with well-made broaches, may be obtained from the following examples, all of which represent actual practice.

Broached Work and Broaching Fixtures. Figs. 1 and 2 illustrate miscellaneous examples of pieces of work that have been finished on broaching machines, and give a fair idea of the classes of work which are usually handled. It is extremely difficult to make any general statement in this connection, because the range of work that is being successfully done on broaching machines is being constantly extended. In Fig. 2 particular attention is called to the piece at the upper right-hand corner. It is made of fiber and is of interest because it is believed to be one of the first cases in which this material has been successfully broached.

As regards work-holding fixtures for use on broaching machines, a considerable diversity of practice is sure to be found, according to the industry in which the machines are used and the nature of the work handled on them. In some cases no fixture is required, it merely being necessary to project the end of the broach through a prepared opening in the work and then to pull the broach through with the work abutting against the faceplate. This is the simplest condition, and the fixture required may be anywhere over a range from this lower limit to a case similar to that illustrated in Fig. 3. In this instance it was required to broach spline grooves in a steel cylinder, and owing to the length of the hole and the unusual toughness of the work, considerable difficulty was experienced in keeping the broaches and the work from becoming overheated.

After experimenting with various expedients, the fixture illustrated in Fig. 3 was finally developed, and it has given quite satisfactory results. The work is a steel tube *A* in which spline grooves are to be broached, and this work is held in position by means of a clamp *B*. Prior to being set up on the broaching machine, the forward end of the work has been machined to fit accurately into a cap *C* that is

Fig. 1. Examples of Work done on Broaching Machines

connected to pipe *D* which delivers coolant under a pressure of 60 pounds per square inch. After the broach has been drawn far enough into the tube so that its outer end will not interfere, a gasket and cover plate are secured to cap *C*, and then the coolant is admitted. Owing to the high pressure to which it is subjected, this coolant is effective in reaching all points of contact between the broach and the

work, thus preventing all tendency toward overheating. An idea of the effectiveness of this high-pressure coolant will be gathered from the fact that the fluid enters the fixture at a temperature of between 58 and 60 degrees F., and after the broaching operation has been completed, the temperature has risen from 78 to 80 degrees F. There is nothing of

Fig. 2. Internal Work finished on Broaching Machines

peculiar interest in regard to this operation with the exception of the fixture design.

Broaching Motor Car Steering Knuckles. In some models of Buick motor cars, steering knuckles are used which are of the forms shown in Fig. 4; and for broaching the openings in these forgings, a fixture has been developed which is illustrated in Fig. 5. The job consists of broaching two

keyways in knuckles of the type where the two openings have a common axis, or one keyway in knuckles of the type where the axes of the holes are in planes at right angles to each other. This operation is performed on a double-head machine, and with a view to expediting production as far as possible, the fixture has been designed to provide for simultaneously broaching four keyways with broaches pulled by each head. The steering knuckles are held on the

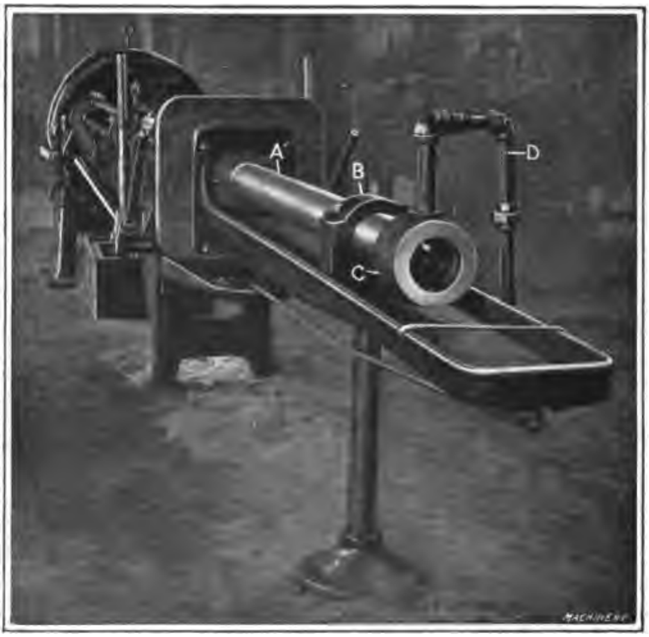

Fig. 3. Broaching Fixture with Provision for delivering Coolant to the Work under High Pressure

fixture by their shanks, and after the draw-head on the machine has come forward, the ends of the broaches are put through the work and secured to the pull-bushings in the head. Each broach is furnished with a guide consisting of a plate on the back of the work which prevents the broach from springing away from the cut. A detail view of this guiding member is shown between the two views of the fixture. It is through the application of multiple fixtures of this type on a double-head machine that maximum rates of

output are attained. On this job the production is 250 steering knuckle forgings per hour.

Broaching Steering Gear Teeth. At the plant of the Willys-Morrow Co., in Elmira, N. Y., broaching machines are employed for cutting the internal teeth of steering gears, the teeth being completely cut in a single operation. Fig. 7 illustrates the broach used for this purpose, and two views of a gear in which the teeth are cut. The work is drop-forged steel, and in order to increase the rate of out-

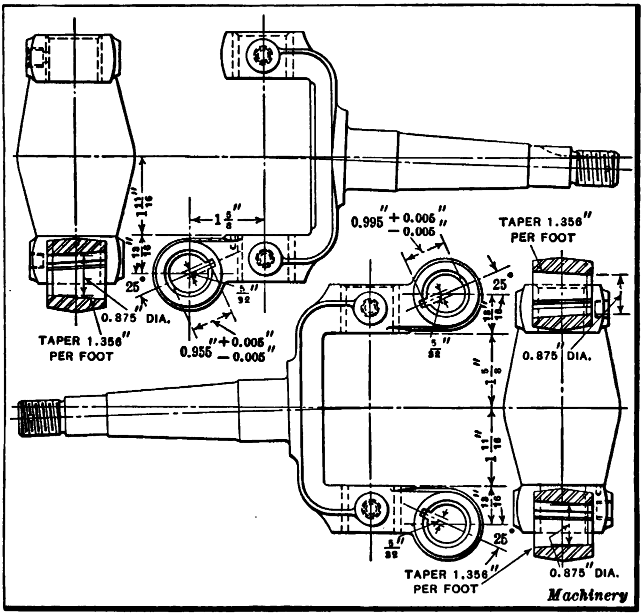

Fig. 4. Two Types of Steering Knuckles in which Keyways are Broached

put, two forgings are stacked against the faceplate on the machine to cut the teeth in both simultaneously. There is nothing unusual about this job, but the rate of production obtained will give an idea of the output that is possible in performing operations of this general character. A double-head machine is used and the teeth are cut in 100 gears per hour. On the larger sizes of gears, the teeth are roughed out on a broaching machine and finished on the Fellows gear shaper.

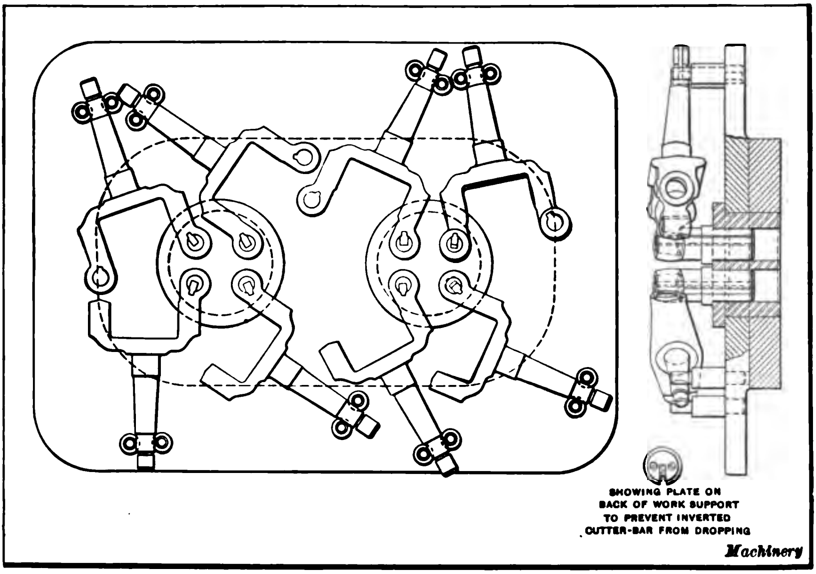

Fig. 5. Fixture for supporting Steering Knuckles while broaching Keyways

Fig. 6. Broaching Six Spline Grooves in Low-speed Transmission Gears

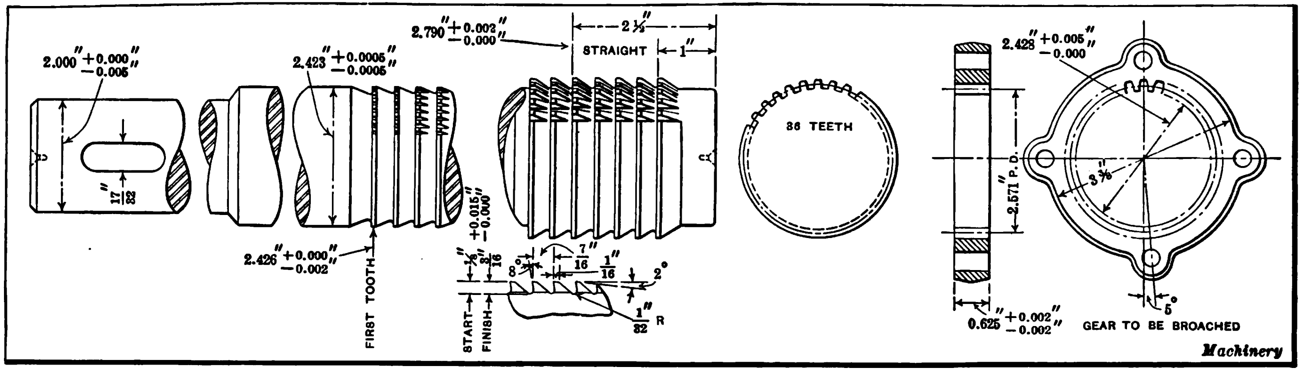

Fig. 7. Steering Gear and Broach used for cutting the Internal Teeth at a Single Operation

Broaching Slots in Stator Frames. The General Electric Co., Schnectady, N, Y., has adopted the use of broaching machines for forming shallow grooves in the interior of cast-iron stator frames for electrical machinery. Fig. 8 shows the machine engaged upon the performance of such an operation, in which nine grooves are machined. In Fig. 9 is shown a stator having twelve grooves which are produced by the same method. One great advantage of broaching these grooves is that it has been found possible to devise a method of procedure which allows all slots to be cut simultaneously, without the necessity of disconnecting the broaches from the draw-head on the machine after each cut has been completed. Reference to the right-hand end of the machine shown in Fig. 8 will make it apparent that a work-holding fixture is provided that consists of a boss or drum, secured to the faceplate of the broaching machine, and

Fig. 8. Broaching Machine equipped with Nine Broaches for simultaneously cutting Shallow Grooves in a Casting

made of the proper size to fit into the opening in the work. This boss has nine grooves cut in it to serve as guides for the broaches.

It will be noted that the ends of all the broaches are connected by compression springs, and as the draw-head moves forward, these springs pull the free ends of the broaches together sufficiently so that the work can be slipped over the broaches and pushed into place on the fixture. Then as the draw-head starts on its return stroke, the guides in the fix-

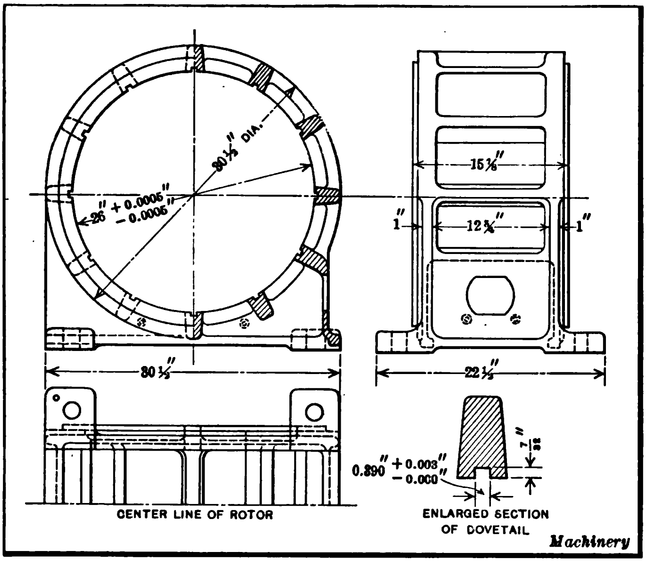

Fig. 9. Stator Casting in which Twelve Grooves are broached on a Machine Similar to the one shown in Operation in Fig. 8

ture hold the broaches up to the cut so that the taper of their teeth results in feeding the broaches inward sufficiently to cut the grooves to the desired depth. The draw-head is returned to its forward position, where the compression springs will pull the free ends of the broaches in sufficiently to allow the finished piece of work to be withdrawn and a fresh casting set up in its place in the manner just described. After the cut has been completed, the work must be removed from the machine before starting to return the broaches to their initial position, as it would not be

possible to back them through the work. A practice is made of designing cutter-bars in such a way that the work will go over the end of them and up on the work bushing, ready to start performing the broaching operation. On this job the rate of production obtained is twelve stator castings per hour.

Obtaining Spiral Form for Broached Grooves. In an earlier chapter, mention was made of three general ways by which it was possible to obtain a spiral form for broached

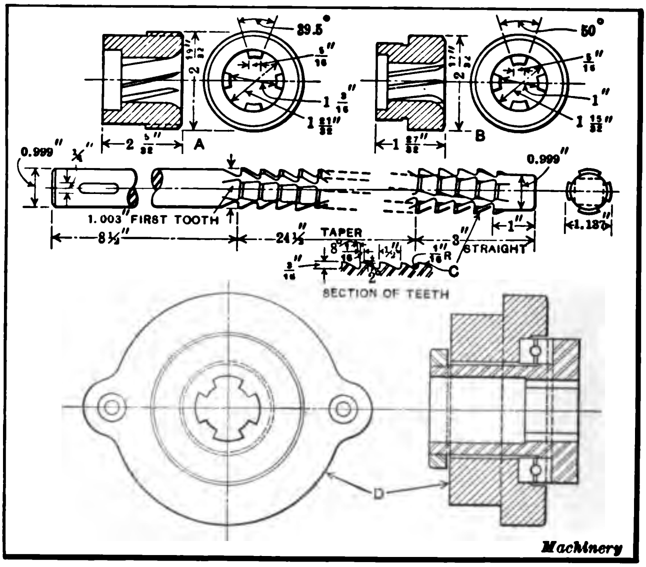

Fig. 10. Broach C and Ball-bearing Thrust Plate D, used for broaching Spiral Grooves in Work shown at A and B

grooves. At the top of Fig. 10 there are shown at *A* and *B* two bushings used in machines built by the Climax Rock Drill & Engineering Works, Ltd., of Carn Brea, Cornwall, England. These bushings are made of casehardened nickel steel, and each has a four-grooved rifled hole in it. Below the views of the work, there is shown the broach *C* used for this operation, which, it will be seen, has the teeth arranged on spirals, the lead of which corresponds to that of the spiral grooves to be cut. To make the work follow the spiral form of the broach, a ball-bearing thrust plate *D* is interposed

between the work and the regular faceplate on the broaching machine. As previously explained, an arrangement of this kind enables the work to follow the spiral of the broach, because as soon as the teeth start to cut, their sides impart a twisting movement to the work causing it to screw on the broach in somewhat the same way that a nut is screwed on the threaded end of a bolt. On this job four broaches are used in sequence to complete the operation, and the rate of production is fifteen finished bushings per hour.

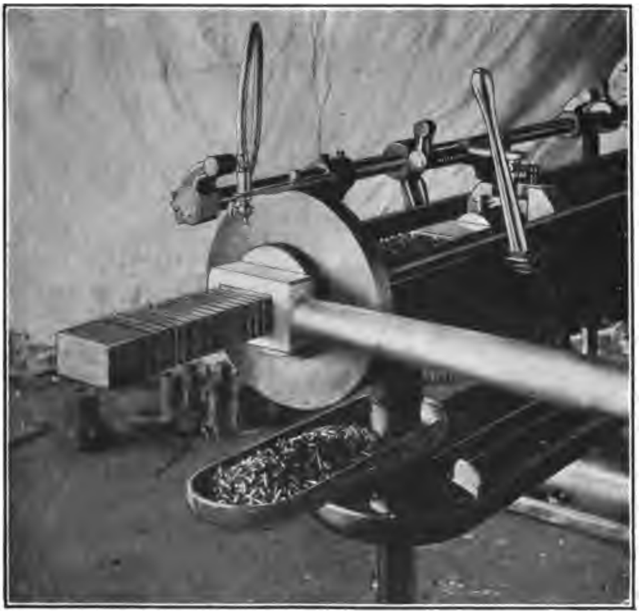

Fig. 11. Broaching Engine Connecting-rod End

Broaching a Connecting-rod End. A simple example of broaching is illustrated in Fig. 11 which shows how the rectangular opening in the end of an engine connecting-rod is finished. The hole is $2\frac{1}{4}$ inches wide by $4\frac{1}{2}$ inches long, and the end of the rod is $1\frac{7}{8}$ inches thick. This rectangular opening is finished by broaching in from four to five minutes, the time depending somewhat upon the facilities for handling the work. The end of the rod, prior to the broaching operation, is either blocked out by jig drilling as indi-

cated at *A*, Fig. 12, or a rough hole is formed by forging as indicated at *B*. The full lines in the plan views show the rough surfaces in each case, and the dotted lines, the finished hole.

For broaching an opening of this size, two operations are required; one for roughing and one for finishing. The roughing broach removes the greater part of the metal and enlarges the hole to within 1/16 inch of the required size, there being 1/32 inch left on each of the four faces for finishing. The starting end of the finishing broach fits into the hole made by the roughing broach. These broaches are

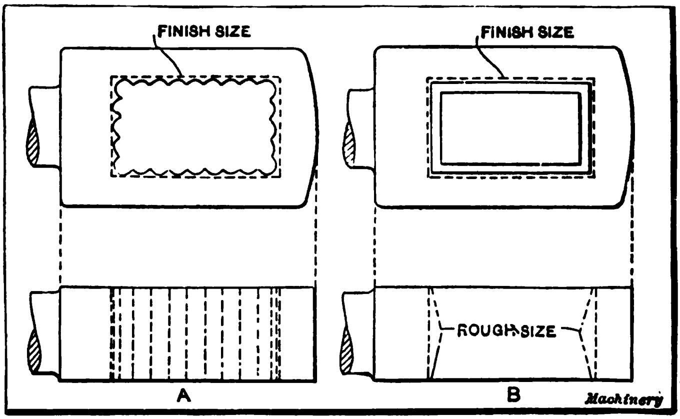

Fig. 12. (A) Rod End Blocked Out by Drilling. (B) Rod with Forged Hole

made of a solid piece of steel and are approximately 48 inches long.

As each of these rods weighs from three hundred to four hundred pounds, they are usually handled by means of a hoist. The end of the rod to be broached is supported by the broach itself, and the opposite end rests on a suitable stand. In this way, the work is held parallel or in position to bring the finished hole in alignment with the rod. The broach operates in a fixed position and finishes the hole according to the way the rod is set. After the support is properly located, any number of pieces can be broached without further adjustment, the holes produced being uniform in size and in alignment with the rod.

Broaching as a Substitute for Milling. An example of a broaching job which might ordinarily be regarded as a typical job for a milling machine is illustrated in Fig. 13. It will be seen that the work *A* is to have a portion of the metal cut away along each edge of its under side. A job of this kind could quite well be handled on a milling machine equipped with two form cutters to straddle-mill the work, and by making a suitable string fixture a very satisfactory rate of output would be secured. Experienced milling machine operators can draw their own conclusions as to the relative

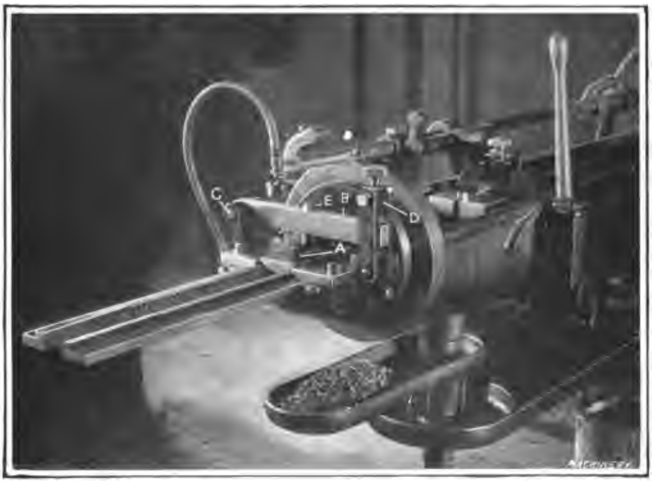

Fig. 13. External Broaching Operation

merits of milling or broaching these pieces, when it is known that on the broaching machine ten of these cast-steel parts are completed per hour. Very little discussion of the work-holding fixture is necessary. It will be seen that strap *B* is pivoted at *C* and provided with a clamping member *D*. After strap *B* has been secured in place, nut *E* is tightened to hold the work in place on the fixture. Of course, it will be evident that each of the broaches is formed to remove a segment of metal of the desired shape.

Broaching out the center of a Small Casting. Fig. 14 shows the equipment utilized for broaching small castings

which constitute parts of a product of the Cleveland Dental Mfg. Co., Cleveland, Ohio. The job consists of broaching out a cored opening in the work. A simple form of fixture is used for this purpose, and reference to the illustration will show that it has a fixed jaw *A* and an adjustable jaw *B* that grip the edges of a flange *C* at the base of the casting, the movable jaw being manipulated by two adjusting screws

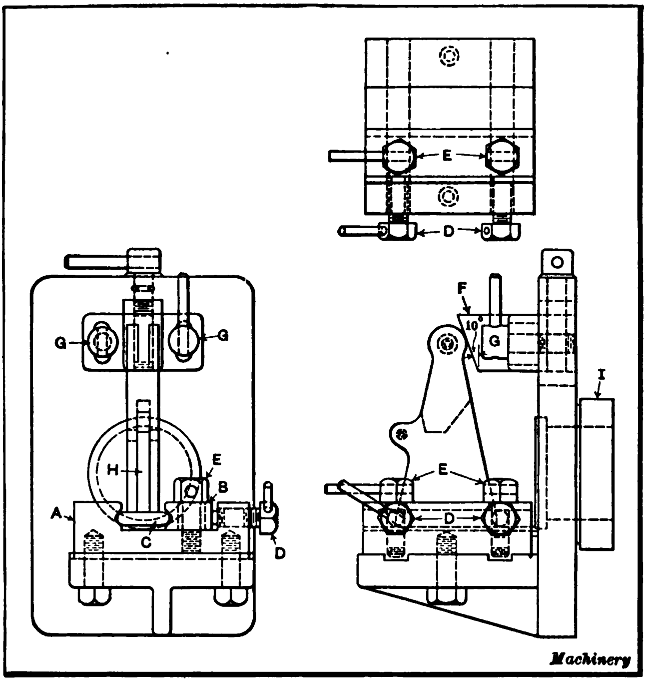

Fig. 14. Work-holding Fixture for broaching out Cored Hole H

D and then clamped in place by tightening two screws *E*. It will be apparent that the work is of considerable height and that this overhang would be sufficient to cause an objectionable amount of springing and vibration if an adequate upper support were not provided. This support consists of a block F mounted on the vertical slide, so that it can be lowered into place against the work, after which binding screws *G* are tightened to maintain a permanent location.

From the front view of the casting held in place in the fixture, it will be apparent that the opening to be broached is shown at *H*, and the broach used for this fixture is of a narrow rectangular cross-section. Following the usual practice, the work-holding fixture is secured to the faceplate on the machine by means of a boss *I* that enters a hole in the faceplate.

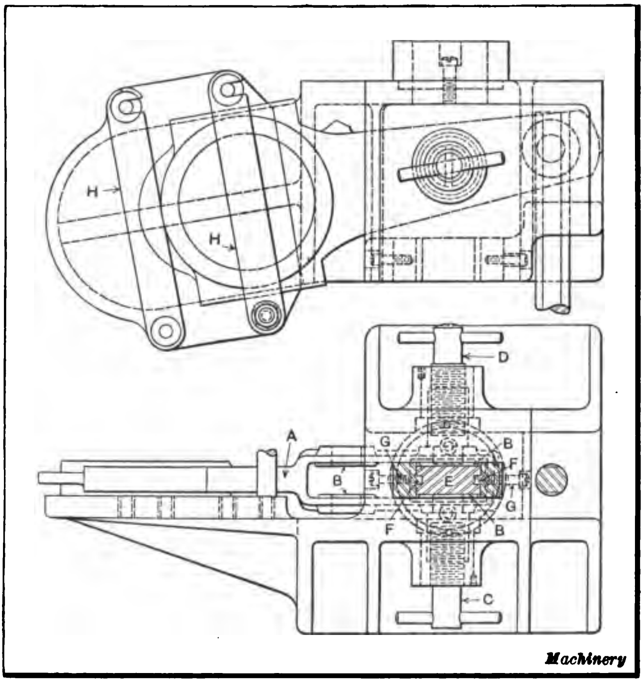

Fig. 15. Finishing the Inside Surfaces of Bosses B on the Broaching Machine

Broaching Inner Faces of Bosses on Eccentric Straps. Another application of a broaching machine for what might ordinarily be regarded as a milling operation is illustrated in Fig. 15, which shows the work-holding fixture for use on a machine used for broaching the inner surface of bosses on eccentric straps. The work is shown at *A* and there are two pairs of bosses *B*, the faces of which have to be broached. Two settings of the work are required to com-

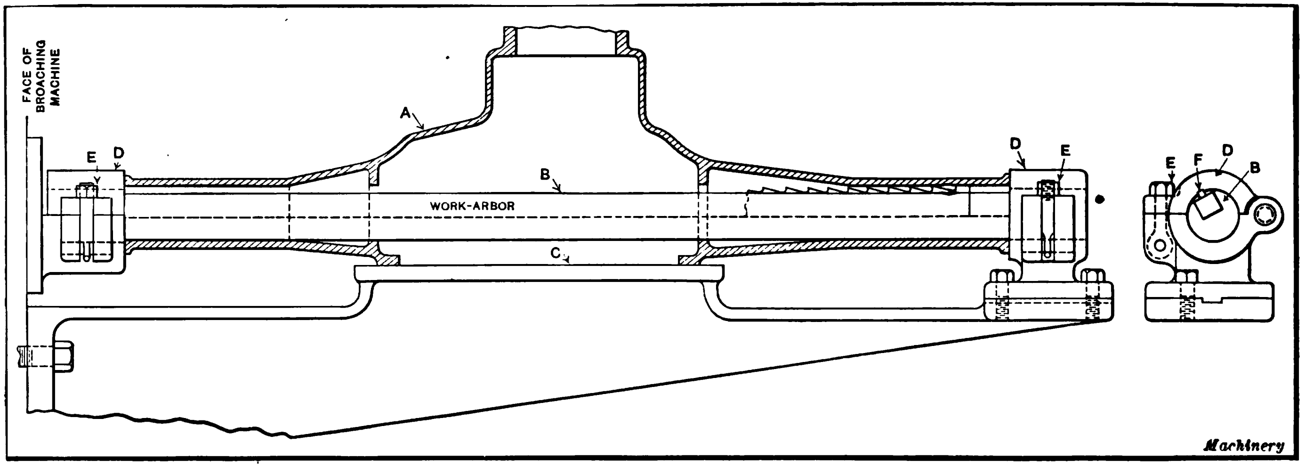

Fig. 16. Reo Rear Axle Housing A is held by Arbor B on Fixture C while broaching a Keyway

plete this job. Owing to the form of the work it is important to provide adequate support to prevent the surfaces to be broached from springing away from the tool. Such provision was made on the fixture by means of two heavy screws *C* and *D*. With the work in place in the fixture, screw *C* is first turned until its end engages the under side of the work; then screw *D* is tightened down on the upper surface. In this way two thrust members are applied to opposite sides of the bosses from those which are to be broached, and there is no possibility of the pressure of the cut causing the work to spring out of place.

The broach is shown at E, and there is a guide member F at each side of the broach, which is held in the desired position by a screw G. After the first pair of bosses has been broached, the work is released and reset in the fixture to bring the second pair of bosses into the operating position. Aside from the location of the work, the method of broaching is identical in each case. The work is clamped in the fixture by two clamping bars H, which are pivoted at one end and provided with C-shaped latches at the other, which makes it necessary only to loosen the binding nuts slightly in order to allow the latches to be swung back to lift the work out of the fixture. The fixture itself is secured in the faceplate of the broaching machine by the familiar method of having a boss on the fixture enter a hole in the faceplate. On this job the work is cast steel, and ten eccentric straps are completely broached per hour.

Broaching Keyways in Rear Axle Housings. Rear axle housings which have to be machined at the plant of the Reo Motor Car Co., Lansing, Mich., require a keyway to be cut that extends the entire length of the work. A broaching machine is used for this job, and Fig. 16 illustrates the work, work-holding fixture, and broach that are used. The rear axle housing A is shown in cross-section. A work-supporting arbor B assists in holding the piece on the platen C of the fixture. In loading the fixture, the work A is first put into place on platen C, after which the arbor B is slipped through the end brackets D and the hole in the work, and secured in place by tightening the binding nuts E. Reference to the end view of the fixture will make it apparent that arbor B is provided with a guide slot to receive broach F. On this job the rate of production is twelve housings per hour.

Broaching the Bearings in a Camshaft Case. Fig. 17 illustrates the camshaft case of an engine built by the Murray & Tregurtha Co., Boston, Mass. This illustration shows the work divided at the center and the two halves placed one beneath the other. There are seven bearings A to be broached, the diameters of which range from 2.1570 to

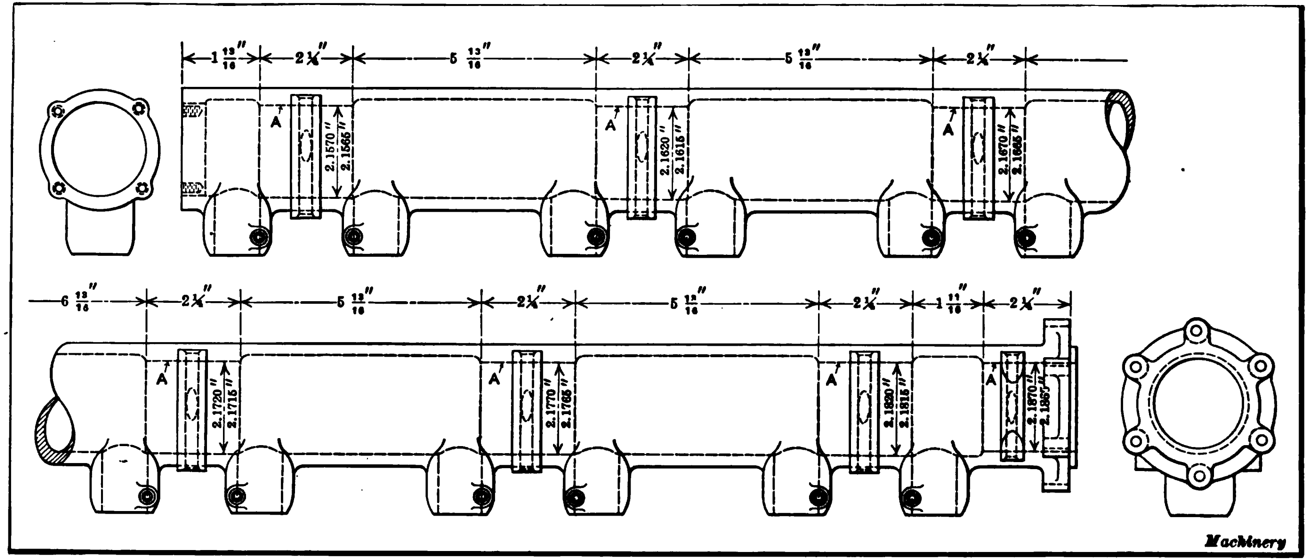

Fig. 17. Cam Frame of an Engine in which Seven Bearings A are finished by broaching

2.1870 inches, each adjacent bearing being 0.005 inch larger than the preceding one. This difference in the size of the bearings introduces a complication in broaching, because of the impossibility of pulling a single broach right through the work. The slight difference in size between bearings that are located adjacent to each other makes it a profitable procedure

first to broach all of the bearings to a standard size equal to that of the smallest bearing to be broached, namely 2.157 inches. After this has been done, a broach with a pilot 2.157 inches in diameter is used to broach all of the bearings except the one at the left-hand end of the work. The pilot on this broach enters the left-hand bearing which has already been finished to the desired size, and the teeth of this broach are so located that they come into engage-

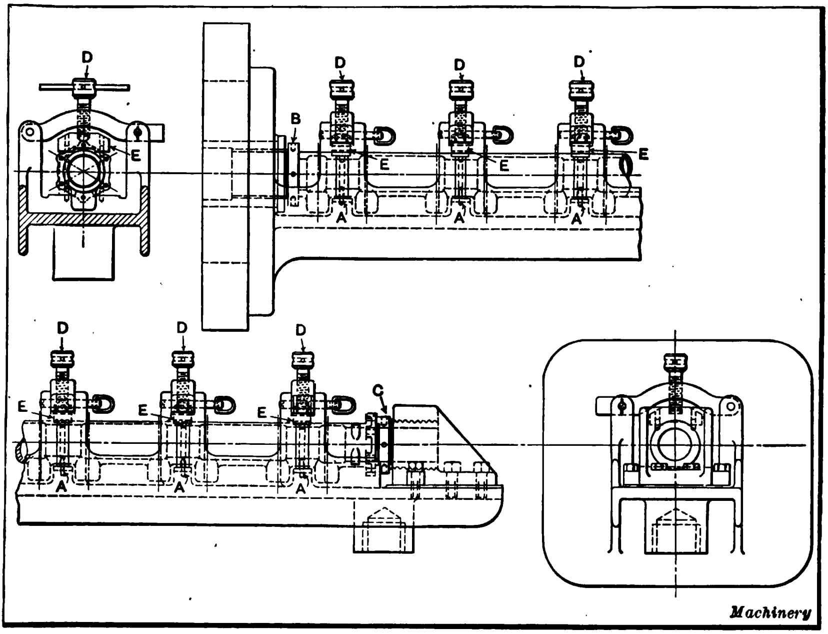

Fig. 18. Work-holding Fixture used on the Broaching Machine for finishing Bearings of the Cam Frame shown in Fig. 17

ment with the last of the bearings that they are to broach immediately after the pilot has entered the finished bearing at the left-hand end.

When the second bearing has been broached in this way, a broach is used for finishing the third bearing from the left-hand end of the work, which has a pilot 2.162 inches in diameter. Similarly, the broaches for finishing the remaining bearings have pilots 2.167, 2.172, 2.177 and 2.182 inches in diameter, respectively.

Fig. 18 illustrates the work-holding fixture that is used to support the camshaft case shown in Fig. 17, while the bearings are being broached. In a general way, this fixture is quite similar to the one described for cutting the keyway in Reo rear axle housings, except that no work-holding arbor is employed. Located at the top of each bearing is an oil-hole and, with the work in the inverted position which it occupies in the fixture, a pin *A* enters each of these oil-holes to locate the work in the desired longitudinal position. Then two threaded collars *B* and *C* are tightened to

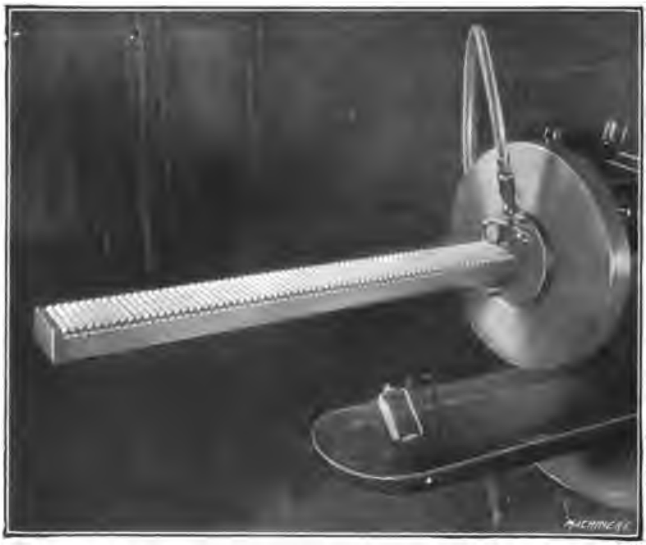

Fig. 19. Broach for Finishing Drop-forging shown in Fig. 20

engage opposite ends of the camshaft case and prevent longitudinal movement while the pressure of the cut is effective. As in the case of the eccentric straps shown in Fig. 15, it is necessary to support the work so that it will not spring away from the broach during the operation. In the present case this result is accomplished by means of clamping screws *D*, each of which carries a yoke *E* that embraces the upper surface of each bearing, while the lower surface is similarly held by its seat in the fixture. With the work secured in this way, there is little chance for the

amount of pressure developed by the broach to cause it to expand sufficiently to introduce a serious error. On this job the material to be broached is an aluminum alloy casting, and the rate of production obtained is four completely broached camshaft cases per hour. This is one of many operations illustrating the application of broaching to classes of work requiring special work-holding fixtures.

Broaching Rack-teeth in a Drop-forging. Fig. 19 illustrates a method of broaching the vacuum cleaner part shown in Fig. 20, the rough forging being illustrated at *X* and the finished part at *Z*. These pieces are light drop-forgings,

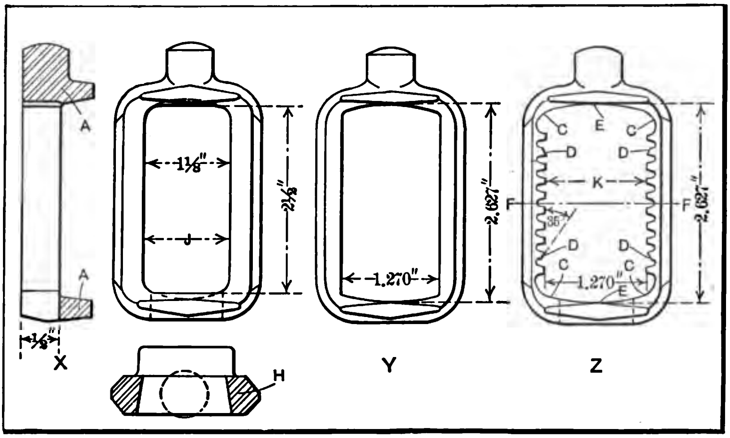

Fig. 20. Method of Broaching a Drop-forging

and the thinness of the metal provides very little support to withstand the strain of heavy broaching. In this operation, not only are rack teeth cut (as indicated at *Z*), but also the clearance at *C*, the angular teeth *D* and the end surface *E*, all of these surfaces being finished at one passage of the broach. In finishing these pieces, it is necessary to have the center line *F-F* equi-distant from the end surfaces *E* and this feature was easily provided for by finishing the pieces on the broaching machine. If the surfaces *E* had been machined by separate operations on any other machine than a broaching machine, there would have been a possibility for the introduction of an error at this point.

It will be seen that the pieces are approximately ½ inch thick and that they have a draft *H* on the inside of the forging. The amount of material removed at the dimension *J* was 0.198 inch on each side. The broaching operation would have been easier to handle if this draft had not been necessary. Attention is also called to the fact that the rack teeth were machined with a degree of accuracy which held the dimension *K* within a limit of 0.002 inch, which is exceptionally close when the lightness of the work is considered. After the first two thousand pieces had been broached, the first and last pieces of the series were checked

Fig. 21. Broaching Machine Finishing Rectangular Hole in Vise Body

in order to determine if any wear had developed in broaching. There was not any error between the dimensions of these two pieces which could be measured. It is stated that in broaching this first series of 2000 pieces, a saving of 80 per cent was made over the time that would have been required to manufacture them by any other method; this saving is net, the cost of the broaches being included in the cost of production.

The broach is made so that the rough forging shown at *X* is first machined to the outline shown at *Y*. After this section is obtained, the clearance at each end, the teeth

and the angular cut on the teeth *D* are machined. The gear tooth section is given very little clearance, so that the broach can be sharpened at the front of the teeth; this feature greatly increases the life of the broach. This broach will machine at least 6000 pieces at a rate of production of about 30 pieces per hour.

Broaching Heavy Bench Vise Bodies. The rectangular hole in the back jaw of an ordinary machinist's bench vise is an interesting example of broaching. A common practice has been to cast the back jaws with the rectangular opening cored as closely as possible to the required size and to fit

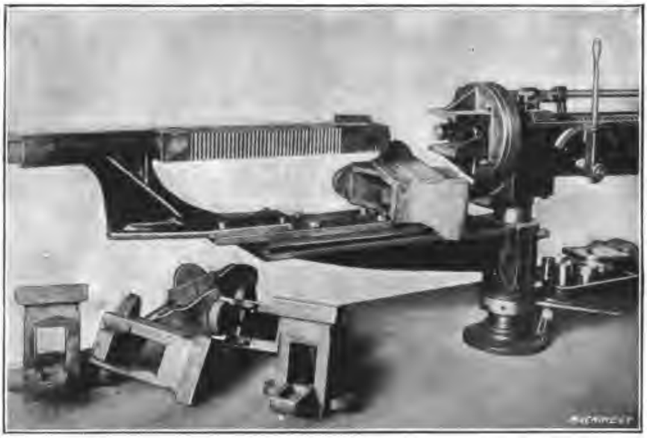

Fig. 22. Showing Heavy Broach supported on Bracket ready for placing Work in Position

the sliding jaw bar to it by filing. The result, of course, is considerable hand labor and more or less unsatisfactory work in many cases. The application of the broaching machine enables the vise manufacturer to cast the back jaws with smaller openings and to remove metal all around the inside of the hole with the broach. This insures perfect bearing and working surfaces free from hard scale.

Fig. 21 shows an equipment used by a vise manufacturer for broaching the holes in heavy vises. The chief feature of interest, aside from the general operation, is the means provided for supporting the heavy broach. The broach

weighs 275 pounds and is, therefore, entirely too heavy to be lifted by hand. The necessity of handling the broach at each operation is neatly avoided. The broach is provided with a round shank at the rear, which telescopes into a supporting bracket. The bracket holds it up in line with the pulling shaft and thus eliminates the necessity of the operator's handling it. The round shank enables the broach to be turned readily to clean off the chips.

The vise jaws weigh about 150 pounds. They are mounted for broaching with the broach in the position indicated in Fig. 22. The broach is then slipped up over the pulling shaft which projects out of the machine and is connected

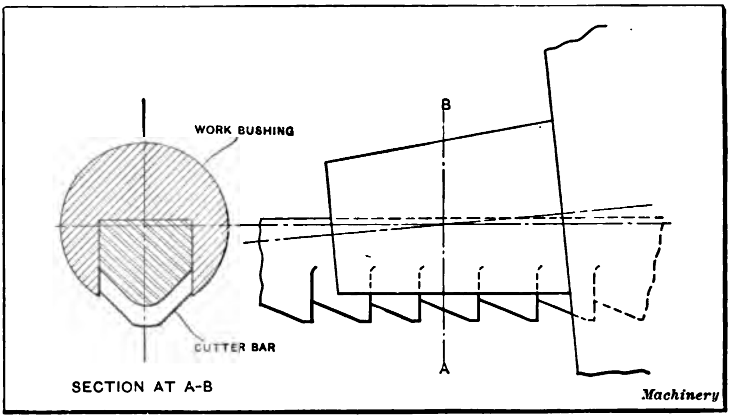

Fig. 23. Device used for Broaching Taper Holes

with a key. As soon as the machine begins to pull the broach through the vise jaw, the teeth come in contact with the metal all around and by the time the supporting shank of the broach leaves the bracket at the rear, the pressure developed is sufficient to hold the broach and vise jaw in position. The bracket for supporting the broach is pivoted on the round column beneath the end of the machine bed, and can be swung around beside the bed and out of the way when the machine is being used on lighter broaching work. The time for broaching a jaw is from four to five minutes.

Broaching Taper Holes. Broaching machines are adapted to the broaching of taper holes when provided with a special

fixture as shown in Fig. 23. The shape of the hole broached in this particular instance is shown in Fig. 24. It is evidently impossible to complete the forming of a square taper in one operation with a solid broach, as this would require a broach made in sections and guided in such a way as to travel in paths at the proper angle with each other to give the required taper. In the case of small work, as that shown, the plan is followed of cutting one corner of the taper at a time, and then indexing the work to four successive positions until each corner has been cut, which thus finishes the entire hole.

As indicated by the dotted lines in Fig. 24, the hole to be broached is first finished with a taper reamer slightly larger

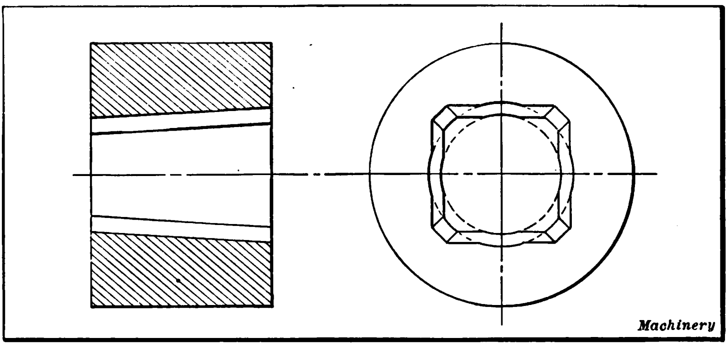

Fig. 24. Taper Hole Broached by Means of the Device shown in Fig. 23

at the large and small diameters than the width across the flat sides of the finished taper hole at the large and small ends. This gives a little clearance space for the broach on each of the operations. This round tapered hole also serves as a seat for the taper bushing on which the work is supported during the cutting operation, and as the broaching does not entirely clean out this hole, the bearing remains to the completion of the final operation. The work bushing is turned on its outside to the taper of the hole in the blank, and is mounted at the head of the machine on a base which is inclined to the angle of the corner of the internal taper to be cut. In a groove formed on the under side of this tapered work bushing, slides the broach or cutter bar (see

Fig. 23), having teeth formed in it after the usual fashion of such tools, smaller at the inner end and gradually increasing in height to the outer end until they conform to the full depth of the cut to be made. The work has a dog with a slotted tail clamped to it which adapts it to engage any one of four pins disposed equi-distantly about the edge of a disk which forms the base of the taper work bushing. By means of these pins the casting is indexed for broaching the four corners.

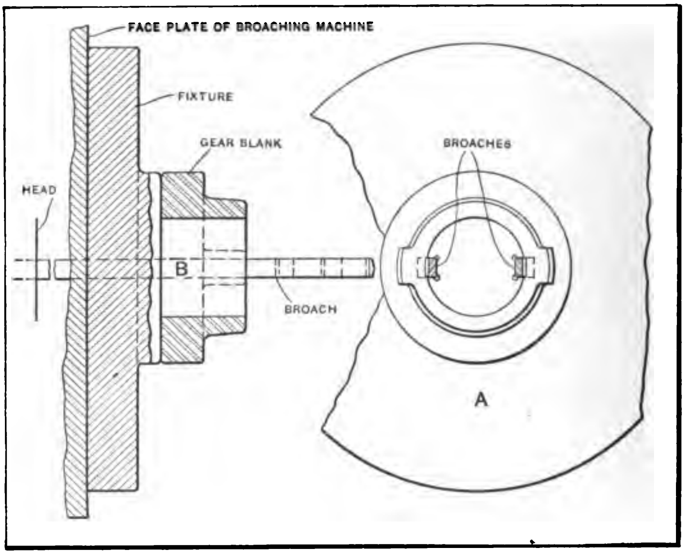

Fig. 25. Fixture used for holding Gear Blanks while broaching Two Keyways in One Stroke of Machine

In operation, the broach having been run out to the extreme end of its travel, the work is placed over the broach, pushed on the taper work-holding bushing, and located in the proper angular position by engaging the dog with one of the four pins. The machine is then started up and the broach drawn back through the work, cutting out one of the corners. Then the broach is again run out, the work drawn off the taper bushing far enough to permit rotating it until the dog engages a second pin, after which the operation is repeated, cutting out a second corner. The

other two corners are successively finished in the same way, thus completing the machining of the hole to the form shown in Fig. 24.

It may be noted that while the hole shown has flattened corners, these are not required, as the broach can be made with a sharp corner if necessary. In all cases, however, it is necessary to leave a portion of the taper hole in the flat of the square so as to center the work with the bushing. Less of the circle, however, can be left than is shown in

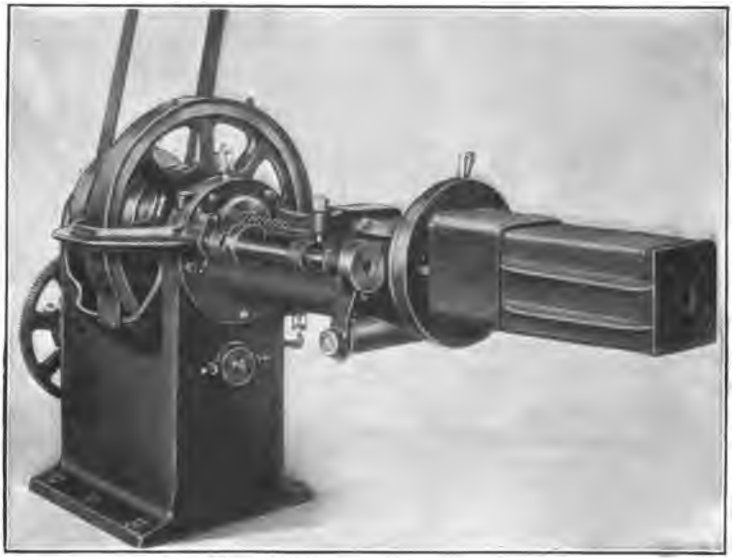

Fig. 26. Broaching Machine engaged in an Exceptionally Heavy Operation

the engraving. For instance, at the large end the round taper hole need be only about 0.010 inch deeper than the square to be cut.

Broaching Keyways in Gear Blanks. An interesting fixture for holding a gear blank while broaching two keyways in it is shown in Fig. 25. This gear blank is made from a vanadium steel drop-forging, and the broaching length is $1\frac{3}{8}$ inches, two keyways which are 5/16 by 5/32 inch being cut in one pass of the broaches. In cutting these keyways it is not necessary to remove the broaches, which are held in

the head, as the operator simply allows the head of the machine to advance toward the fixture, then grips the two broaches, which closes them together, and slips the work over.

The broaches *B* have no teeth for a distance of about 2½ inches from the face of the fixture, so that when these are held together it is a simple matter to slip the work over them and locate it on the fixture *A*. It is evident that when the head of the machine travels away from the fixture, the broaches are drawn in, and as they are made thicker toward the outer ends, they cut the keyways to the correct depth.

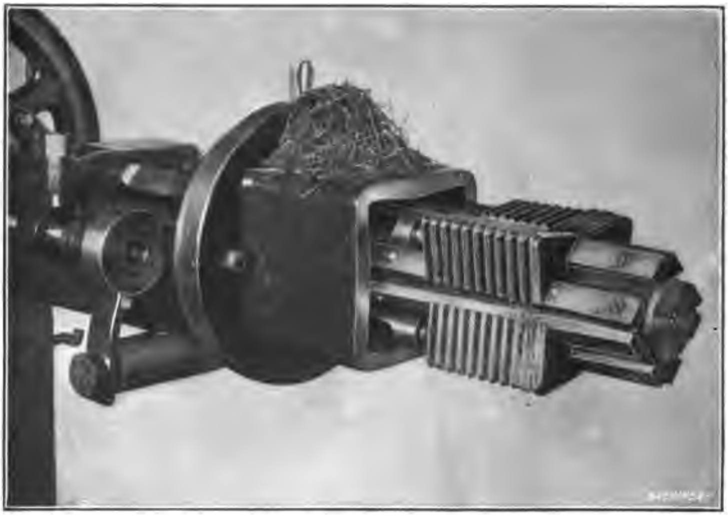

Fig. 27. Taper Broach used for Broaching the Steel Casting shown in Fig. 26

The illustration shows how these broaches are guided when in operation on the work. Holding the broaches in the manner shown enables a large production to be obtained, the time generally taken in removing and replacing the broach being saved. On an average, 800 gear blanks are broached in ten hours, which means that 1600 keyways are cut in this time. The possibilities of broaching when suitable fixtures are provided are almost unlimited, and the job just described illustrates the adaptability of the broaching method to the cutting of keyways in gears.

Broaching a Large Steel Casting. Figs. 26 and 27 show a broaching machine provided with special cutting tools, and engaged on an exceptionally heavy broaching operation. The size of the hole to be broached is approximately 8 inches square, though the hole is not really square, being of the special shape shown in Fig. 28. Not only is the work remarkable on account of its size, but also because the surfaces had to be broached on a taper, the outer end of the hole being 1/2 inch further across than at the bottom, while the work is rendered still more difficult from the fact that the opening is closed at the small end. The method of broaching this casting is to begin at the bottom and work outward. A recess 3 inches long and about 1/4 inch deep is furnished at the bottom to provide a clearance space for starting the broach. The amount of stock to be removed on each of the finished surfaces of the work is about 1/16 inch; the total area to be broached is 14 inches long, with a developed width of 24 inches. In the center of each face of the hole, it will be noticed that there is a half-round recess; no broaching is done in this part. This operation illustrates the possibilities of broaching as applied to large work.

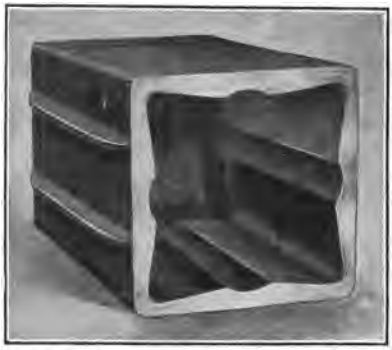

Fig. 28. Large Steel Casting broached as illustrated in Figs. 26 and 27

The machine used is an unusually large size which operates on the same principle as the machines previously described. The mechanism consists primarily of a threaded draw-bar or ram, operated by a revolving nut, driven by suitable gearing and reversing mechanism, this mechanism being operated by dogs and adjustable stops to give the required length of operating and return strokes. Practically the only special feature of the equipment is the broaching head and broaches used. These are of such unusual size and ingenious construction as to be of decided interest.

The construction of the broaching head is plainly shown in Fig. 27. It consists essentially of a central square mandrel, tapered to the taper of the hole to be finished in the work, and provided with ways in which slide four separate broaches—one for each corner of the work. These broaches are connected with the head of the machine ram by bars, which are milled down thin to have sufficient flexibility to permit the broaches to spread apart as they approach the inner end of the stroke, and come together again as they return to the starting position on the outer end of the mandrel. Each of the broaches is made of a solid piece of tool steel, with a series of 13 teeth of suitable shape milled in it.

In operation, the ram is first extended to the outer limit of its stroke, with the broaches at the outer and smaller end of the square central mandrel. The work is then placed over the mandrel as shown in Fig. 26, in which position the broaches nearly touch the closed bottom of the hole. The outer teeth in this position are in the recess at the bottom of the work. The machine is then started, and the revolving nut and threaded ram pull the broaches up on the tapered guides of the square mandrel by means of the flexible pulling rods. As the broaches are thus drawn inward on a gradually expanding form, they cut the required shape in the interior of the steel casting. The broaches first are tapered, so that the outer end is 1/32 inch larger than the end to which the pulling rods are connected, this being the amount which is to be removed from the work in each operation.

As is shown in the illustrations, a special abutment or base is provided for taking the thrust of the work as it resists the action of the cutters. Piled up on this special base, in Fig. 27, will be seen the chips produced at one stroke of the machine. It will be noted from their character that a cutting action is effected by the broaching blades. The approximate pulling strain on the four rods operating the broaches is estimated to be from 75 to 100 tons.

Broaching Round Holes. The broaching of round holes has been adopted within the last few years by many manu-

facturers on certain classes of work, in preference to reaming. This change is due to two reasons: The cost of the operation is less and the finish on the particular work referred to later is superior to that of reaming.

It is an acknowledged fact that the boring and reaming of seamless steel tubing, especially when the walls are light, is not a very satisfactory operation; in fact, the pieces are usually distorted, due to the method of holding them. One of the principal objections to reaming, and one reason why it is so hard to obtain a well reamed hole in steel tubing, is that the reamer tears or "bites in" at some point on the surface. This is due to the fact that the fibers of the steel are drawn lengthwise or at right angles to the cutting edges of the reamer.

On the other hand, when broaching the hole in a tube, a very nice finish can be obtained because the fibers lie or are drawn in the same direction as the broach is operated. The ordinary seamless steel tubing is about 0.008 to 0.030 inch under standard size, which is about the right amount to broach out. For broaching this material, with diameters up to 2 inches, the high speed of the broaching machine can be used, the cutting tool traveling at about six feet per minute. There is no clamping of the work for this operation and the shell is not distorted as much as it would be by boring or reaming. Six or seven pieces can be broached in the time necessary to ream one.

Broaching vs. Reaming. When finishing a hole by reaming, the cutting edge of each reamer blade travels a distance approximately equal to the circumference of the hole multiplied by the number of revolutions or turns made by the reamer in passing through the work. In the case of a round broach, the distance traversed by any point on the broach in machining a hole is equal to the length of the work; hence, it can easily be seen that broaching is a much faster operation than reaming, especially when the broach has a cutting speed of at least four feet per minute; moreover, the broach will maintain its size for a longer period than a solid reamer, because the finishing end of the broach has a number of teeth of the same diameter, and as these only take very

light finishing cuts they are subjected to very little wear. Even an adjustable reamer has no longer life than a well made round broach.

The part shown at *A* in Fig. 29 is a steering pivot for the front axle of an automobile. The hole is $5\frac{1}{8}$ inches long

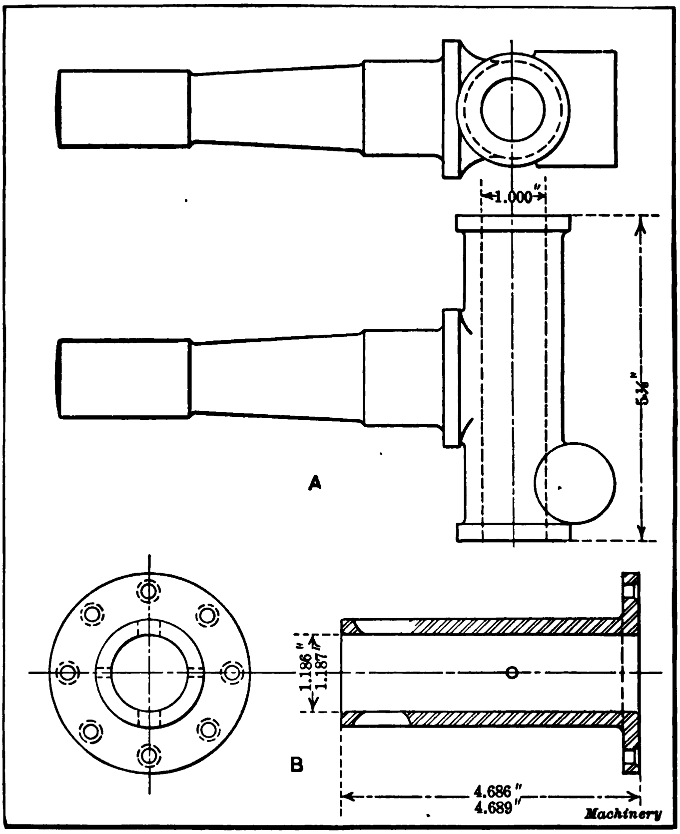

Fig. 29. Examples of Work machined by broaching

and 1 inch in diameter. These pivots, at one time, were machined by first drilling the holes with two drills of different diameters which were followed by a rose reamer and a machine reamer, but even with these four operations, the hole was not finished straight and a hand reamer had to be used to secure satisfactory results.

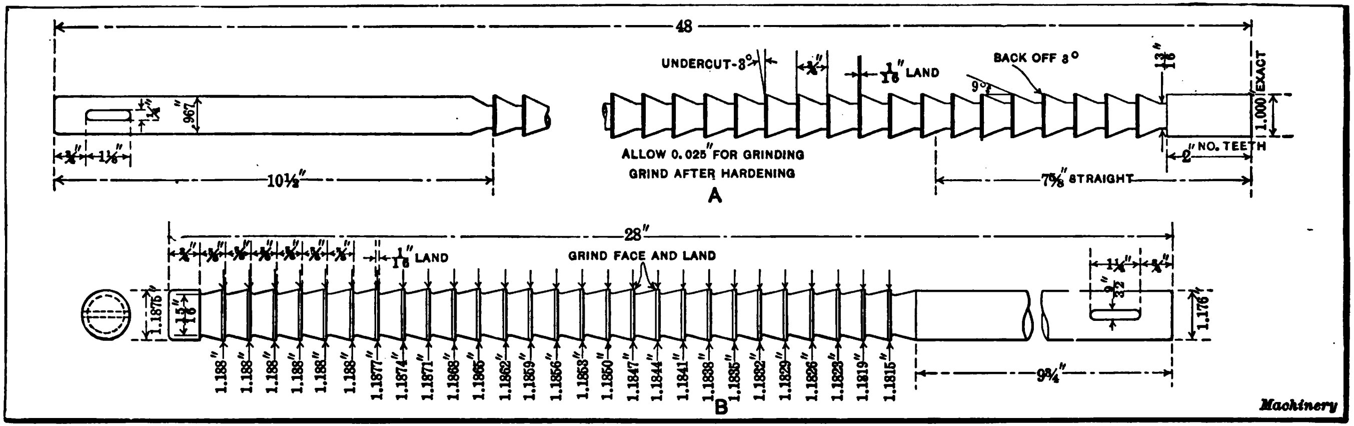

Fig. 30. Broaches used for Parts Illustrated in Fig. 29

Prior to the broaching operation, the pieces are roughly drilled 1/32 inch under size. The result is that the work does not need hand reaming and is produced more cheaply and with a better finish than could be obtained by such an operation. In this case, the broaching was done before any of the other machining operations. The material is chrome-nickel steel. The broach used for this piece of work is illustrated at *A* in Fig. 30.

The example of work shown at *B* in Fig. 29 is another automobile part that is made of vanadium steel. The average production of these parts by broaching was sixty per hour, and one broach machined as many as 7685 pieces before it was worn too much for standard work. The dimensions of the broach used are given at *B* in Fig. 30.

Broaches for Round Holes. The results obtained when broaching round holes depend on the tool itself. The broaches are ground all over after hardening and are backed off at the proper angle to give them a nice cutting edge. The teeth are nicked to break the chips on the heavy cutting part of the broach, but the last six or eight teeth that do the sizing are not nicked. Following the last six or eight sizing teeth is a short pilot which supports and guides the broach. One very important thing in broaching round holes is the proper spacing of the broach teeth. The broach must always be made up with differential or uneven spacing of the teeth. If the teeth are all evenly spaced, as a rule unsatisfactory results will be obtained.

When making broaches a number of things must be taken into consideration, viz.; material to be cut, length of work, amount of stock to be removed on the outside, and the shape of the work, so that the proper support can be provided. The length of the broach depends entirely on the metal to be removed. Of course in cases where the broaching operation is for sizing, a short broach is used, usually having about 10 inches of cutting edge. If the broach is to remove 1/8 inch of stock, the length may vary from 28 to 40 inches, depending on the length of the work.

Broaching Round Holes in Steel Gears. The method of machining the holes in sliding and differential gears, adopted by one of the largest automobile gear manufacturers in the country, is as follows: The work is placed in a suitable fixture on a drilling machine and the holes, which vary from 1 1/16 to 1 1/2 inches in diameter, are drilled in one operation with a drill 1/32 inch smaller in diameter than the finished size of the hole. On the spindle of the machine a facing head is arranged so that after the hole is drilled, the spindle is fed down and the gear faced off; this forms a flat surface which is square with the hole and is used for locating the work while the holes are being finished by broaching. The old method was to drill these gears, bore the holes and then ream them. The reduction in cost obtained with the new method is 1 1/2 cent per hole. The results obtained by broaching are that a well finished

hole is obtained in addition to greater production; moreover, the life of a broach is eight to twelve times that of a reamer.

Broaching Round Holes in Bronze Bearings. Another operation of broaching round holes is that of finishing holes in bronze machine bearings, up to about 2½ inches in diameter. Take, for instance, the broaching of a 2-inch round hole in bronze castings 4½ inches long. It is the practice in one shop to allow ⅛ inch of stock to be removed or 1/16 inch on each side, the hole being cored ⅛ inch smaller than the finished diameter. When these bearings were being bored and reamed to size, ¼ inch was allowed and the aver-

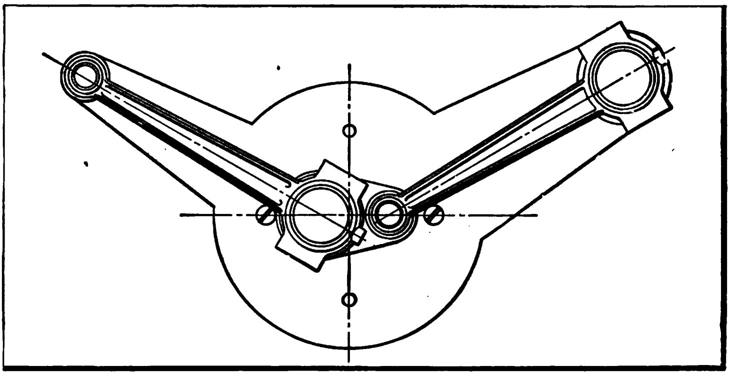

Fig. 31. Engine Connecting-rods, and Fixture for Broaching

age time was 10 minutes per piece. They are now broached at the rate of one in 1¼ minutes without clamping the pieces and they do not lose their shape. The finish of the broached holes is better than was obtained by reaming. The trouble when reaming hard bronze is to overcome the chattering and waving of the reamer in the hole; this has been done by broaching.

Broaching Round Holes in Chrome-nickel Steel. It has been demonstrated that the broaching of hard chrome-nickel steel, such as is used in automobile work, is a much cheaper process than reaming. A typical job is shown in Fig. 31, which illustrates two connecting-rods and their broaching fixture. The small end of one rod and the large

end of the other are broached simultaneously and one complete rod is finished for every stroke of the machine. The fixture is not absolutely necessary but adds considerably to the production. These connecting-rods are first drilled to the size of the broach shank or to a diameter of from 0.015 to 0.018 inch under the required size. They are then finished by broaching, thus eliminating both machine and hand reaming. After the rods have been broached, the large end is split and the lining bushing for the large end is inserted. The bushing for the small end is pressed into the rod. These bearings or bushings are then broached. The finish obtained can be duplicated only by scraping, although

Fig. 32. Finished Connecting-rods broached as indicated in Fig. 31

broaching is, of course, much cheaper, and the metal is compressed somewhat, thus giving the bearing a hard, glazed surface that resists wear. A number of finished connecting-rods are shown in Fig. 32.

The broach illustrated at *A* in Fig. 33 is used for broaching the hole in the large end of the rods, whereas the smaller broach *B* is for finishing the bushing. The plain round sections seen on these broaches are for the purpose of keeping the broach from "running" or "crawling," as it is essential that the center-to-center distance of these rods be kept fairly accurate. By introducing plain blanks or sections between the teeth, as shown, the broach is kept properly aligned with the hole because there is always some

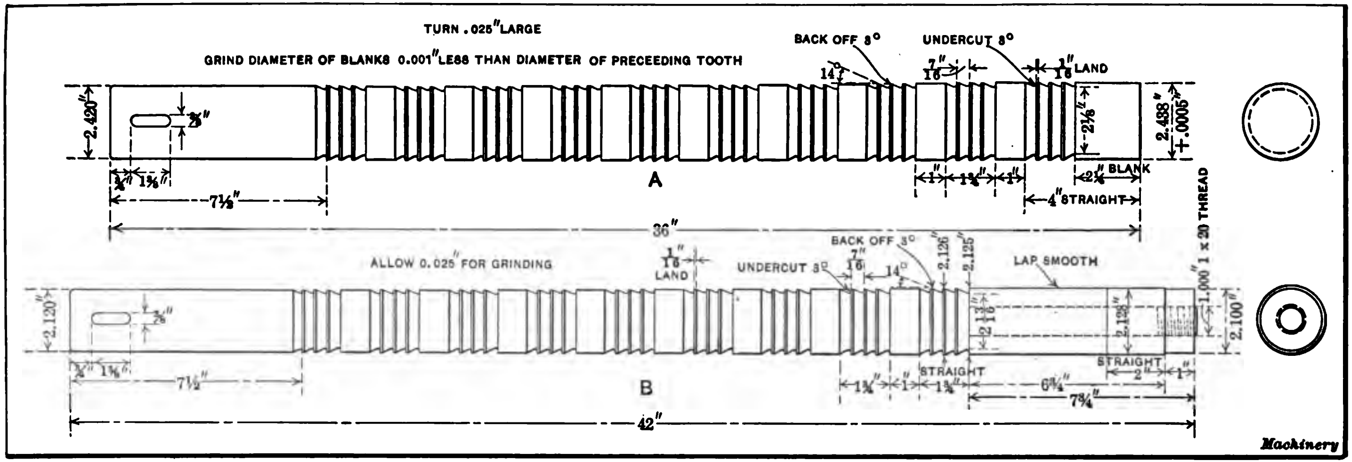

Fig. 33. Broaches used for Connecting-rods shown in Fig. 31

portion of the blank section in the work while some of the teeth are cutting. In other words, the blank sections serve as guides and prevent lateral movement.

When using a broach, the small end is passed through the work and fastened to the draw-head of the machine by a cotter-key which passes through the slotted end in the usual way. Only such clamping as is necessary to support the work is required as the blank sections on the broach will hold the part in alignment. When using these broaches in cast iron, a soap cutting compound is used, as this gives the broached surface a highly polished finish. For chrome-nickel steel, a good

grade of cutting oil will give satisfactory results. On some work, no drilling whatever is done prior to broaching, and very often only one broach is used, but if the work is longer than say two inches, a roughing broach usually precedes the finishing broach. Of course, broaching from the rough can be done only when the broaching operation comes first, as the broach follows the rough hole and, consequently, the finished hole will be out of true with any other surfaces which are machined prior to the broaching operation.

Another Connecting-rod Broaching Operation. Fig. 34 shows the fixture used by the Willys-Overland Co., Toledo,

Fig. 34. Using Follow-rest for keeping Broaches in Alignment when broaching Connecting-rods

Ohio, for broaching both ends of the connecting-rods at one time. This fixture is quite similar to the one illustrated in Fig. 31. The hole in the large end is $1\frac{7}{8}$ inches in diameter by $1\frac{3}{4}$ inches long, while the hole in the small end is $1\frac{1}{8}$ inches in diameter by $1\frac{1}{2}$ inches long; 0.040 inch of stock is removed from the diameter of each hole, and the cutting speed of the broach is 40 inches per minute. The production is 400 connecting-rods in nine hours.

An interesting attachment consisting of follow-rest A is employed to keep the broaches in proper alignment so that the correct center distances between the two holes in the

connecting-rods will be obtained. The broach for both holes is provided with lands to support it and keep it straight, but this was not sufficient to prevent the broach from having a slight whipping action, causing the holes to be slightly out of line. This follow-rest is free to move on a special base comprising two ways on which the rest slides, which has been attached to the machine. The broach for the large hole is fastened to the follow-rest which keeps it straight in line, whereas the smaller broach is free to slide in the rest, but as the latter is tied to the large broach, it is carried toward the head of the machine as the broaches are drawn through the work. The broaches, which are approximately 47 inches long, were found to dull very quickly and produce a poor hole before this attachment was added to the machine. By keeping the broaches straight and supporting them in this manner it was found that their life was materially increased, and the production was practically doubled.

Broaching Round Holes in Vanadium Steel. The following example represents the practice of a large automobile manufacturer in the broaching of round holes in vanadium steel forgings. The forging, which is 5½ inches long, is first rough-drilled in a high powered vertical drilling machine, from 0.005 to 0.010 inch being left on the diameter of the hole to be removed by the broach. The forgings are taken from the drilling machine to the broaching machine and the hole, which is 1 3/16 inches in diameter, is completed in one pass of the broach, a production of 750 being obtained in ten hours.

The fixture used is of simple construction, consisting simply of a cast-iron ring fastened to the faceplate of the machine, against which the forging is held by the broach as it is drawn through. A small straight portion about 1¼ inch in length is provided on the end of the broach, which passes through the hole and gives it a burnished appearance. The hole is superior as a bearing surface, to that produced by a reamer. This is because when the reamer is working in alloy steel, especially that containing a percentage of nickel, it usually tears rings around the hole, producing a rough

surface. The broach, on the other hand, if it scratches or tears at all, makes these in a line parallel with the axis of the work, which is less detrimental to a bearing surface than annular grooves. Another advantage of broaching round holes instead of reaming them is that the broach retains its size much longer than a reamer.

A Special Broaching Operation. The progress which has been made in the broaching machine and its use is illustrated by a broaching operation which is performed at a factory where universal joints for automobiles are manufactured. Fig. 35 shows two plan views of the piece which is to be broached, showing the work done at each of the two opera-

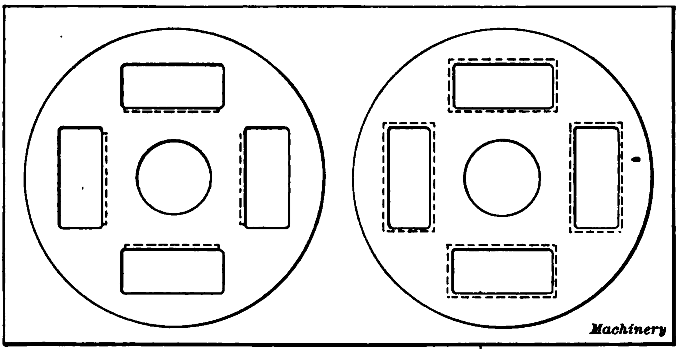

Fig. 35. Plan View showing Four Rectangular Holes which are finished by Two Broaching Operations

tions. Fig. 36 illustrates the special broaching fixture and broaches used for doing the work. Part *E* is the rough steel forging upon which the broaching is done. This is one of the parts of a universal joint. It is one inch thick, having four roughly formed rectangular holes, which must be broached on all four sides, finishing each hole to an accurate size; moreover the broaching must be so done that the finished holes will all be equi-distantly spaced from the central hole. This central hole is finished by drilling and reaming and the outside edge of the piece is turned, so that the piece may be held by the edge.

Referring to Fig. 36, it will be seen that the broaching fixture consists of a very heavy faceplate casting *A* that fits

on the head of the broaching machine, and this casting is bored out to receive the other half of the fixture *B*, which acts as a guide-sleeve.

The faceplate *A* is fitted with four hardened steel guides *C* which are adjustable radially by means of set-screws *D*. It will be noticed that these guide-blocks are slotted to receive and guide the broaches while they are cutting. The piece to be broached, indicated at *E*, is a snug fit for the smaller bored hole in casting *A*, allowing it to seat close to the guide-blocks *C*. After being placed in this recess, guide-sleeve *B* which is a sliding fit for the large bored section in faceplate *A*, is inserted. This part of the fixture is also

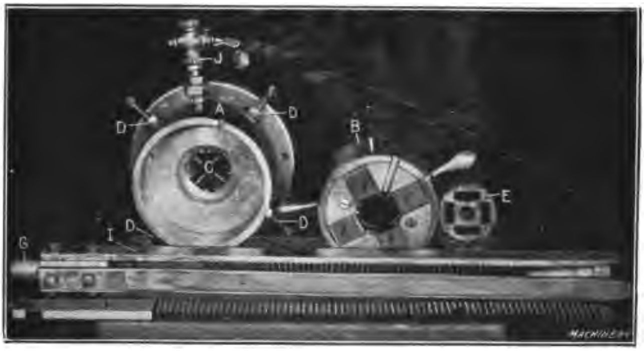

Fig. 36. The Broaches and Broaching Fixture used for the Operations Illustrated in Fig. 35

provided with four hardened steel guide blocks *F* which may be adjusted radially after the manner of chuck jaws. Guide-sleeve *B*, while free to slide in faceplate *A*, is prevented from turning and throwing the two sets of guide-blocks out of line, by means of suitable tongues.

There are two operations required to complete the broaching on this piece. At *G* is shown the broach holder with the four broaches *I*, used for the first operation. One of the features of this job is that four cuts are made at each draw of the machine. The first operation is performed after adjusting the position of jaws *C* and *F*, so that when the four broaches *I*, held on broaching head *G*, start to cut, they will clean out a place on the inside edge of each

of the four holes, leaving the forging with four cuts as indicated by the dotted lines in the left-hand view in Fig. 35. It will be seen that by adjusting the guide-blocks *C* and *F*, against which the blank sides of the first operation broaches bear, the broaching may be controlled as regards its distance from the central hole in the forging.

This completes the work done at the first operation. The second operation is performed with the aid of four broaches, one of which may be seen at *H*, which are held upon the same broaching head *G*. These broaches are provided with

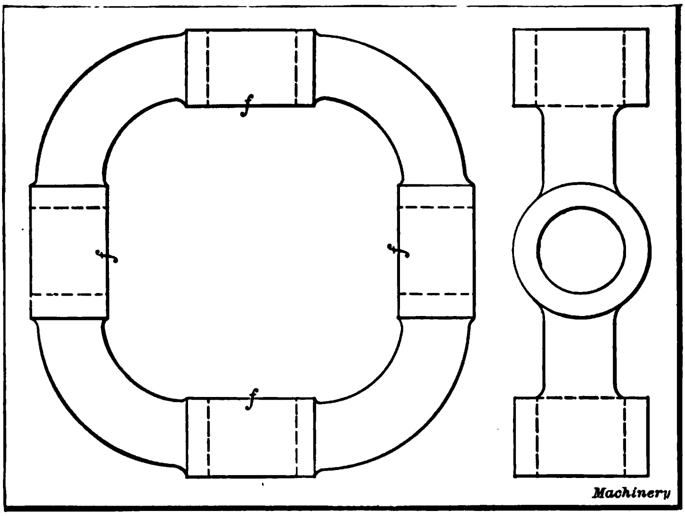

Fig. 37. Ring-coupling of Universal Joint

one flat side which bears against the surface already broached. Teeth are provided on the opposite side and the two edges, so that the other three sides of each of the four holes are broached out true with the four surfaces already broached, thus cleaning the holes out on all four sides and insuring that the finished holes will be true with the central hole. Lubrication is provided through pipe *J* which enters the faceplate casting opposite the cutting point.

In broaching these parts, the entire lot is run through the first operation and then the broaches are changed and the second operation performed. The broaches are not re-

moved from the machine after each pass, because, as they do not cut to the full width of the hole, and as they are spring-tempered and beveled at the ends, they may be pressed together and the forging slipped over them to the starting point. The broaches are made of slightly different lengths so that they do not all begin cutting at once. These pieces are broached at the rate of thirty-six operations, or eighteen completed pieces per hour.

Broaching Flat Surfaces. As has been previously stated, the operation of broaching is too often viewed in the light of a process used principally for cutting keyways or square

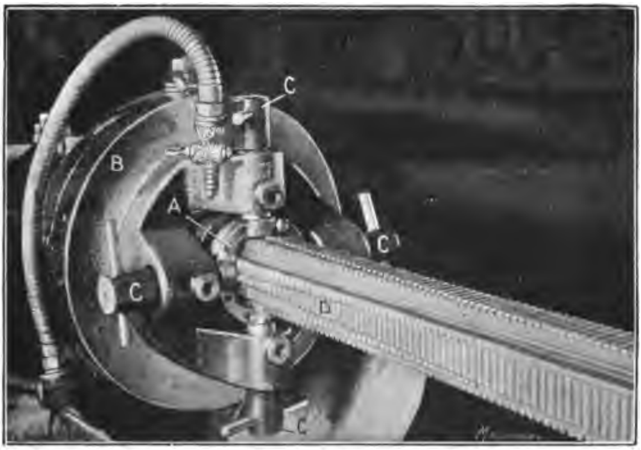

Fig. 38. Broaching Fixture for the Ring-coupling

holes, but with proper equipment the broaching machine is really a machine tool capable of handling a great many otherwise impracticable jobs. Incident to the manufacture of automobile parts there are many interesting broaching operations.

One of these jobs consists of broaching the inside of a ring-coupling which is another part of a universal joint. The ring-coupling, which is shown in Fig. 37, has been previously drilled and broached through the four round holes and it is essential that the inside faces (marked *f*) be finished true with the holes. In order to accomplish this successfully, the work is held upon a special fixture which is

mounted upon the faceplate of a broaching machine. Fig. 38 illustrates the method of holding and broaching the work. The work, shown at *A*, is supported on the fixture *B* by means of four pins *C* which engage the holes in the coupling. These pins are merely a sliding fit through the bosses of the fixture, and the cross handles are added to assist in withdrawing them. The broach itself is shown at *D* and is pulled through the work in the usual manner. In order to facilitate centering the broach in the work as well as to distribute the cutting over the length of the broach, the cutting surfaces of the teeth are made very narrow at the beginning of the tool, gradually increasing in width until at the end of the work they are full width, finishing the

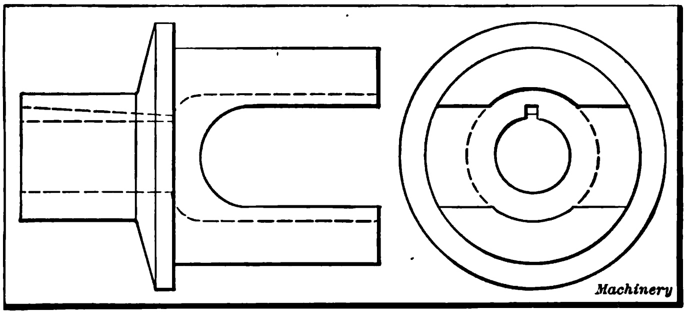

Fig. 39. Universal Joint Yoke in which Tapered Keyway is to be Broached

entire surface. These pieces are broached at the rate of twenty-five per hour and the surfaces are finished true with the holes.

Broaching a Tapered Keyway. Cutting the tapered keyway through the yoke shown in Fig. 39 is a broaching operation that has some interesting features. The keyway is cut at an angle of 10 degrees, the cut being 5/16 inch deep at the beginning and only 5/32 inch deep at the end of the cut. The method of doing the work is illustrated in Fig. 40, in which the yoke is shown in the foreground and also on the machine at *A*. It is supported on the special fixture *B* which consists of a faceplate provided with a leaf *C* that is hinged at *D*. This leaf is held in an upright position by a clamp *F* and the work fits closely in the bushing in the leaf.

As the broaching must be done at an angle to the machined hole, the leaf of the fixture is not held at right angles to the broach, but is backed up by a tapered wedge E so that the work is rigidly held at the required angle to the broaching tool.

When broaching, the work is placed in the leaf of the fixture and the tapered plug G is entered into the hole of the

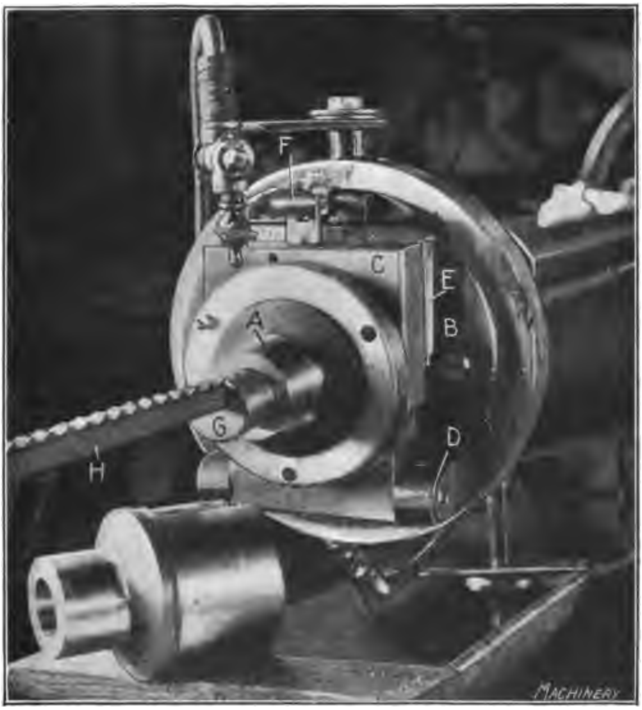

Fig. 40. Broaching the Tapered Keyway

work. This plug is cut out to receive the broach H, and serves as a guide, preventing the broach from springing away from the work. The broaching is then carried on in the usual manner. When broaching must be done at a different angle it only requires the substitution of a wedge of the required angle at E. Thus the fixture can be used on more than one job. This broaching operation is performed at the rate of thirty-three pieces per hour.

Broaching a Round Hole in Alignment with Other Surfaces. The universal slip-hub shown in Fig. 41 is first rough-drilled throughout its length. It is necessary, however, that this hole be finished true to size and exactly in line with the projections at the end. This is accomplished by broaching as shown in Fig. 42; in this illustration the piece may be seen lying beneath the fixture. The fixture which is shown at *A* has a leaf *B* provided with an adjustable bushing *C*. The leaf is dropped and the work placed within the fixture so that the projecting lugs are centered. Then the leaf is replaced and secured with pin *G*, and the bushing is screwed up against the work so that the countersunk inner end will engage the piece at the outside edge and hold it in a central

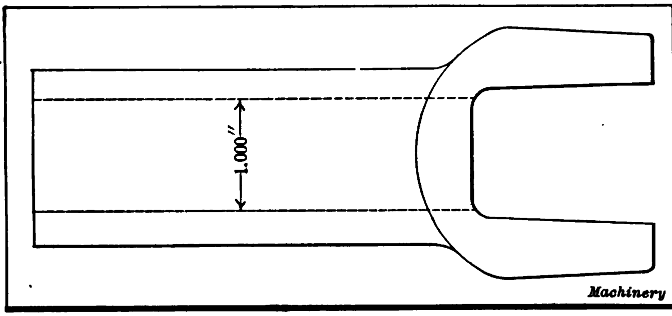

Fig. 41. Slip-hub in which the Round Hole is finished by broaching

position ready for broaching. The broach is then inserted and one pass finishes the piece, leaving it exactly to size and finished as smooth as if done with a reamer. Twenty-five broached pieces per hour is the rate of production.

Broaching a Dovetail Keyseat in a Taper Hole. It was desired to broach a dovetail keyseat in the crankshaft hole of a large quantity of bicycle cranks. The cranks were of nickel steel and had a 10-degree taper hole in the hub, with a minimum diameter of 17/32 inch. It was necessary to broach the hub to receive a flat key, 3/8 inch wide by 1/16 inch thick, dovetailed to a 10-degree included angle. When the keys were driven into place in the cranks, the latter were required to be interchangeable on the crankshafts, which were slabbed off on one side of the taper end to cor-

respond with the key in the crank, and fitted with an ordinary check-nut to retain the crank.

To fit a key in this manner and insure interchangeability and a simultaneous fit on both key and crank, requires a nice degree of accuracy; considering this, and the toughness of the steel, as well as the necessarily limited diameter of the broach, it was expected that the operation would prove expensive. Subsequent experience with the use of the device here illustrated, however, proved otherwise, as thousands of the parts were broached most successfully at a remarkably small cost.

Fig. 42. Broaching Fixture for the Slip-hub shown in Fig. 41

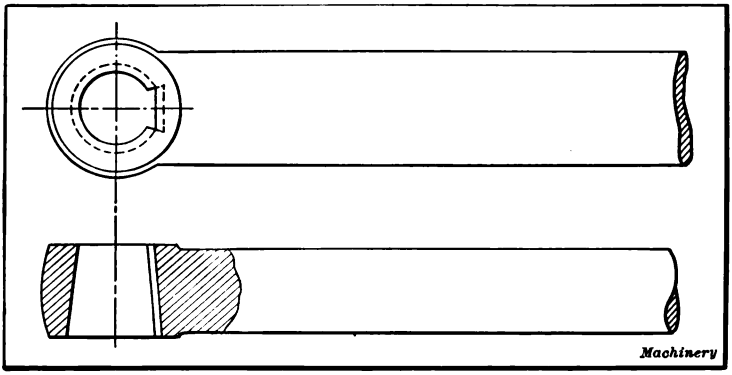

Fig. 43. Bicycle Crank, in Hub of which Dovetail Keyseat is broached

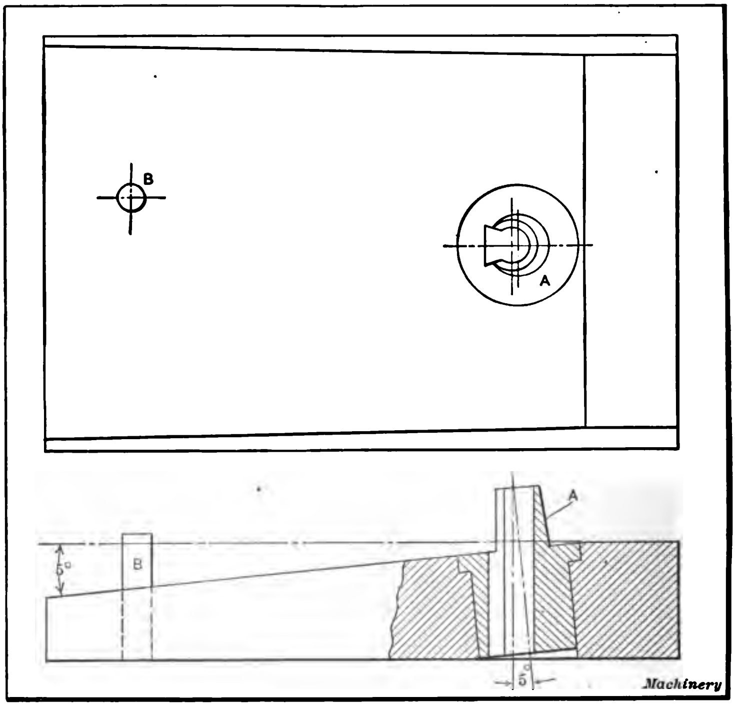

Fig. 44. Fixture for holding Bicycle Crank while broaching Keyway

Fig. 43 shows the piece to be broached. Fig. 44 shows a machine steel plate, planed on the bottom and sides to fit the die-bed of an ordinary 8-inch stroke drawing press, and planed on the top to an angle of 5 degrees. After the plan-

ing operation a hole was bored at right angles with the top surface, to receive a hardened guide bushing *A*, which was pressed into place. The guide hole for the broach was then put through at right angles with the bottom of the plate. Thus it will be seen that when the crank is placed in position over the guide bushing and brought into contact with the stop pin *B*, the surface to be broached will be parallel with the line of travel of the broach.

Fig. 45 shows one of a series of three broaches which are required to complete the cut. These are made to slide freely through the guide bushing *A* (Fig. 44), and are held in the proper position in the holder *D* by means of a locating piece *C*. As the press reaches the limit of the downward stroke,

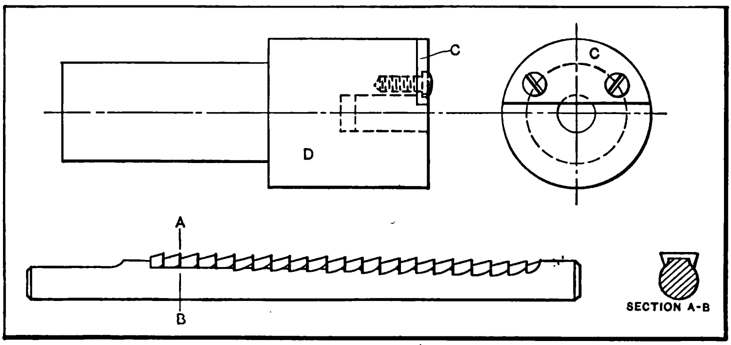

Fig. 45. Broach and Holder used for broaching Bicycle Crank

the broach, which has ceased cutting, simply drops through the bushing into the hand of the operator, who then inserts broach No. 2 into the holder as the press reaches the upward limit, thus making it unnecessary to stop the machine to insert the tools. Great care should be taken to keep the teeth of broaches of this kind free from chips, which can easily be accomplished by the operator's passing his fingers downward over the face after each removal from the guide bushing, and before depositing in the pan of oil.

In hardening broaches of the shape used in this operation, the best results can be obtained by slowly heating the piece, face downward, in a charcoal fire. When heated face upward, the piece will invariably bend, making the

face concave, and as they must be reasonably hard, it is a difficult matter to straighten them.

Broaching a Bearing Ring. The rough forging for a bearing ring and a finished ring are illustrated in Fig. 46. In machining these forgings, a prominent automobile parts manufacturer has reduced the labor cost materially by the application of broaching in machining the inside surfaces and the four holes through the ring.

The rough forgings are made from 0.25 to 0.30 per cent carbon open-hearth steel. The first operation consists of machining the surfaces *A* which come in contact with the fixture used in broaching the inside flat surfaces of the ring in the second operation. The broaching fixture is illustrated in Fig. 47 and consists of a faceplate which holds the hardened steel block *B*. This block guides the broach, and the finished surfaces *A* on the forging, Fig. 46, are also held in contact with the block to locate the work properly. A set of three broaches is used; the first broach takes a coarse chip because the cut is relatively narrow; the second broach takes a finer chip; and the third broach, which has the maximum width of cut to deal with, removes but 0.001 inch of metal. The last seven teeth of this broach are straight while only the last three teeth of the first two broaches are straight. Accuracy in this operation is particularly important not only because it is employed to finish the forging, but the four surfaces finished by broaching are used in locating the work for all subsequent operations.

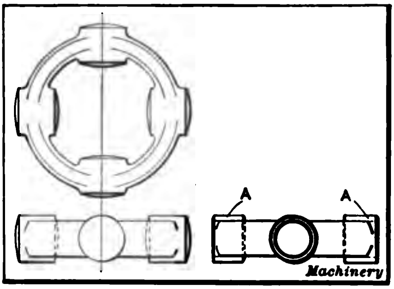

Fig. 46. Bearing Ring Rough Forging and a Finished Ring

The next operation consists of finishing the outside flat surfaces of the ring and is performed on a milling machine. At the completion of this operation the part is taken to a horizontal drilling machine where a 31/32 inch diameter hole is drilled through each boss.

After the holes have been drilled, the forgings are transferred to another broaching machine where the four holes are broached to 0.999 inch in diameter. In performing

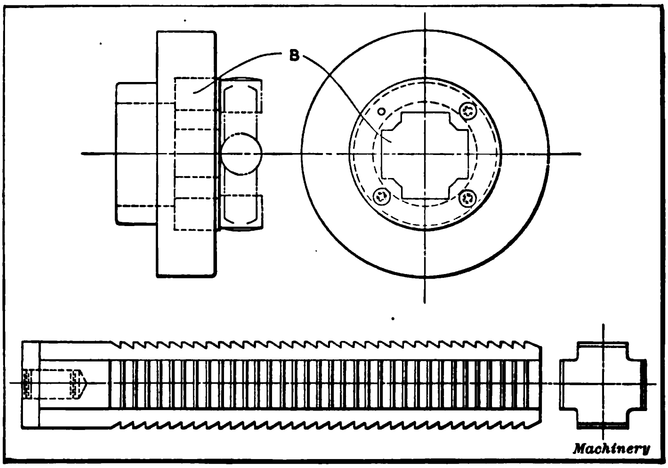

Fig. 47. Broaching Fixture and One of the Broaches used for finishing the Inside of the Forgings

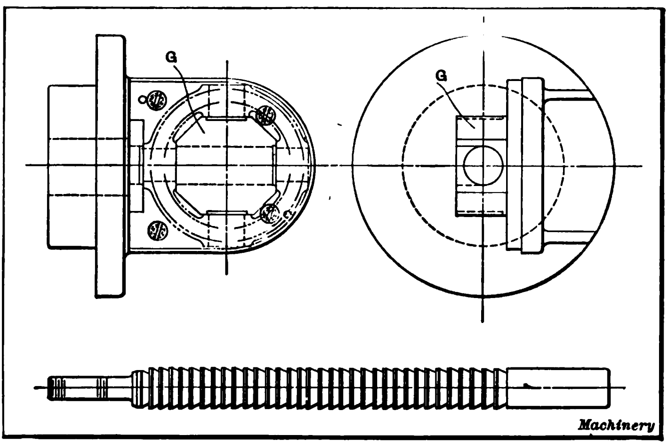

Fig. 48. Broach and Fixture used for broaching the Four Holes in the Forgings

this operation, the work is held on a hardened plug *G* of the fixture shown in Fig. 48. This plug also has holes in it to allow the broach to pass through in finishing the holes on opposite sides of the forging. Nothing in the way of an

indexing mechanism is attempted on this fixture, the work being lifted off the plug and replaced in position for broaching the other two holes.

After the broaching has been completed, the burrs are removed from the forgings by the tool shown in Fig. 49. The lower cutter *A* is made with a square hole in it. This cutter is placed in position and the arbor with the fixed cutter mounted on it is entered through the upper hole in the work and moved down until it enters the hole in the lower cutter. After the operation has been performed in this position, the work is moved three times in order to finish the faces of the other three holes.

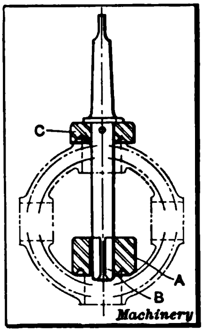

Fig. 49. Tool used for the Burring Operation

The original method of machining these pieces was to first drill and ream the holes on a four-spindle drilling machine provided with two drills and two reamers. Four box jigs were used in a row on this machine. The second operation consisted of profiling the inside of the forging, a fixture being used for this purpose which had four locating pins. In the third operation, the flat surfaces on the inside were broached to the required size, the work being located by a fixture with four pins as in the preceding case. The fourth operation consisted of rough- and finish-milling the outside faces of the forgings on a hand miller, which milled one face at a time. In the fifth operation the holes were broached to the required diameter of 0.999 inch, and after this had been done the final operation was performed, which consisted of removing the burrs.

The substitution of broaching for profiling in finishing the inside of the forgings has not only effected a saving of time, but it requires less manual labor and produces more satisfactory work. There was a tendency to chatter in finishing the inside of the forgings on the profiler.

Built-up Broaches for Broaching Splined Gears. In the plant of the Brown-Lipe Gear Co. of Syracuse, N. Y., there are some interesting spline groove or multiple keyway

broaching operations performed on automobile gears. Fig. 50 shows two of the broaches for this class of work.

One of these broaches, that shown on the machine, is for broaching six grooves spaced equidistantly around a two-inch hole. The unusual feature of this tool is that the broach is built up of sections, each marking the width of a combined tooth and space of the complete broach. These rings are assembled on a bar of soft steel, being keyed

Fig. 50. Two Types of Broaches for cutting Spline Grooves in Gears

so that they will always remain in proper alignment. Should one of the teeth break at any part of its cutting edge, it is only necessary to insert a new section. The sections are all held firmly together by drawing them into place with a nut on the end of the broach arbor. In broaching, trouble is often experienced from having the finish end of the broach, that does the final sizing, wear under size. With this type of broach, however, when the finish sections wear

small, new teeth may be substituted, and the tool is then as good as new. While expensive to manufacture, this style of broach has a long life, the one shown having been in use for the past three years.

Another broaching tool for cutting spline grooves is the one that the operator is shown supporting in an upright position. This is made with six separate broaches that work together in broaching the grooves in a gear having a large center hole. If the broach had been made solid, it would have required a heavy piece of steel, which, of course, would have been costly. The method used was to construct a head-block of low-carbon steel, having slots in which the six narrow broach-strips are hinged. This head-block is pinned to the end of the pulling screw of the broaching machine. The broaches are guided by a slotted block that is seated in the faceplate of the machine. This block may be seen located part of the way up the tool. The broach strips are made tapering as regards thickness from the teeth to the back, the difference in thickness between the two ends of the broach strip agreeing with the depth of the keyway to be cut. When the broaches are started they barely graze the gear, but as they increase in thickness at the cutting point, the broaching takes place. The slotted guide block prevents the broaches from springing away from the cut. The gear is put in place for the operation by slightly springing the tips of the broach strips together and passing the blank on and up to the faceplate of the machine as in some of the examples presented in the foregoing.

Both of these broaching operations are handled rapidly, the average time for broaching a gear 7/8 inch thick, with six spline grooves being but two minutes.

Broaching Teeth of Internal Gears. Broaching the teeth of internal gears will be the next operation to be considered. The gears were 10.666 inches pitch diameter with sixty-four teeth of 6 pitch; and the forgings were made from alloy steel. The teeth to be broached were 1 1/8 inches long and the difficulty consisted of designing a fixture which would hold the work in such a manner during the operation that when it had been completed, the teeth would mesh perfectly

with the pinion and the whole forging would not be distorted. It will be seen from Fig. 51 that the fixture consists of a main casting *A* bolted to the faceplate of the broaching machine. On the inside of this casting there is a cast-iron part *B* which acts as a guide and support for broach *C*. Carried in support *B* is a hardened steel plate *D* which is a loose fit in the holder. This plate is milled on its under side to fit a taper seat in support *B*, and as the broach is drawn through the work, plate *D* is held in its seat and maintains the broach in the proper position to cut teeth of the desired depth. When the return stroke of the broach is started, plate *D* is pushed back in its taper seat and falls out of guide *B*, thus allowing the broach to drop down out of contact with the work.

In broaching internal gear teeth with this equipment, three gear blanks are set up in holder *E* and the blanks are secured in the holder by ring *F*. It will be seen that there are six clamping bolts in holder *E*, which provide for clamping ring *F* in place. In order that the clamping bolts will only have to be loosened in removing ring *F*, holes are provided in the ring of sufficient size to permit the ring to be passed over the heads of the bolts when replacing it, after which the ring is given a slight turn to the right, which results in sliding the bolt heads over slotted extensions of the holes. The bolts can then be tightened to secure the ring and work in place. Reference to Fig. 53 will make it apparent that the broach consists of a frame *A* in which are mounted six broaches *B*. As there are sixty-four teeth in these gears and each passage of the broach through the gear results in cutting six teeth, it will be apparent that eleven passes of the broach are necessary in order to complete the cutting of the teeth. For indexing the work, holder *E*, Figs. 51 and 52, has eleven slots milled in its periphery, which are tapered on both sides so that latch *G* will index the work accurately when it drops into one of these slots.

When the use of a broach of the type shown in Fig. 53 was decided upon, the idea was to provide for the replacement of broken broaches at a minimum expense. Should it

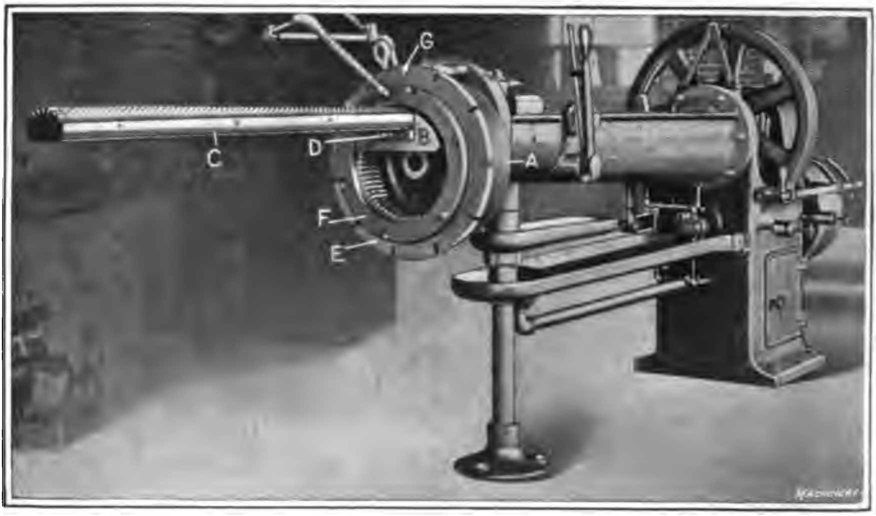

Fig. 51. Broaching Machine equipped for broaching Teeth of Internal Gears

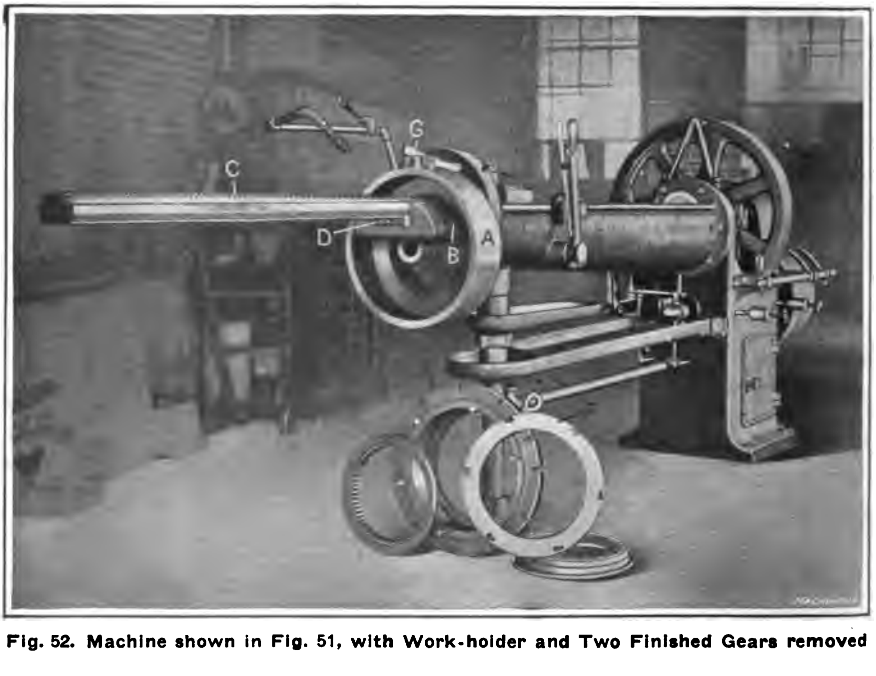

Fig. 52. Machine shown in Fig. 51, with Work-holder and Two Finished Gears removed

happen that a tooth in one section of the broach is broken, this section of the broach can be replaced at a much lower cost than to make

a complete new broach. These broach sections are first planed to standard dimensions and then drilled in four places so that the entire set of six broaches can be bolted into the frame, which is carefully milled to the right width and depth to receive them. At the left-hand end of the frame in Fig. 53, it will be seen that there is a piece of steel *C* inserted for the broached sections to rest against. These sections are shouldered at the ends so that they fit under piece *C*, provision being made in this way for holding the head ends of the broach sections firmly down in the frame. After the sections have been made, they are put into the frame and bolted in place, so that all sections are drawn firmly together to form the equivalent of a single

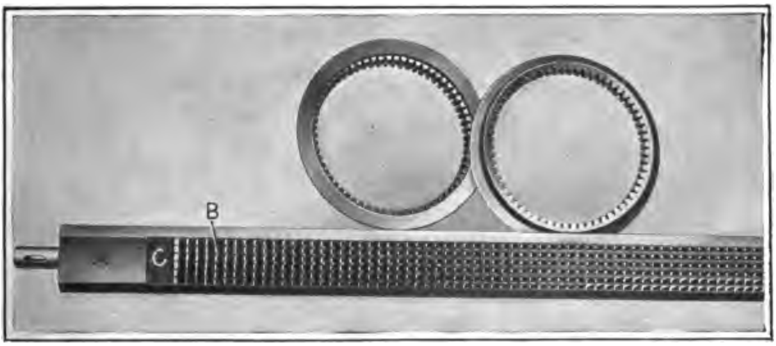

Fig. 53. Close View of Broach and Two Gears Broached on Machine

piece. It is then necessary to turn the outside of the broach sections to the proper radius of curvature and also to cut the teeth. After this has been done, transverse slots are cut to form the cutting edges. The broach sections are then taken out of the frame, hardened and ground on the sides, after which they are once more assembled and ground on the faces and tops of the teeth to obtain the desired height and thickness for the teeth. The speed of this operation naturally depends somewhat upon the skill of the operator in setting up and removing the gears, but a rate of nine gears per hour has been attained by an unskilled operator.

Broaching Square Taper Holes in Brake Levers. The brake lever in the Pierce-Arrow automobile is secured to

its shaft by a square taper seat, being bolted in place. The method by which this square taper hole is cut is interesting. The operation is illustrated in Fig. 54. A faceplate fixture, having four slots equidistantly spaced around the circumference, is clamped on the head of the machine at the proper angle of the taper. The brake lever is first drilled with as large a hole as possible, and before being put on the machine is fitted with a removable steel key that engages one of the four slots just mentioned. The broaching cut is started

Fig. 54. Square Taper Broaching Operation

with the lever in one of the four positions. A cut is taken that cleans out one corner of the hole at the required taper, and the lever is then shifted to the next position and a second cut taken. This procedure is followed until the four cuts have been made, when the lever is removed from the faceplate and the key taken off and fitted to another lever. The result is an extremely clean and well finished hole. The operation does not require a skilled operator.

Broaching Jewelers' Rolling Mills. The W. W. Oliver Mfg. Co., Buffalo, N. Y., manufactures several sizes of jewelers' rolling mills. In the lower right-hand corner of Fig. 55 may

be seen the castings for three sizes of housings for these rolls. The machining of these housings includes the finishing of the slots in which the roll bearing slides and also the finishing of the inside faces that limit the end play of the rolls. It is plain that if the rolls are to work properly these surfaces must be finished accurately and, above all, the cuts must be parallel.

Until the method of machining described in the following was adopted, this work was accomplished by milling, but it was slow, and necessitated the employment of an awkward extension milling rig that reached through the housing.

Fig. 55. Broaching Housings of Jewelers' Rolls

Fig. 55 shows how the job is successfully handled in one-tenth of the milling time, on a broaching machine. Fig. 56 was taken at close range and shows how the work is held in the first operation. Fig. 57 illustrates the construction of the broach and the method of supporting the work. The latter is held in place by clamping tongues *A* which are run in to engage the slots at the sides by means of hand-screws *B*. The broaching operation is performed in the usual manner, and after the lot of housings has been broached in one direction a faceplate is put on the machine to hold the work for taking the cut in the other direction through the slots in the housings.

These slots are broached with solid broaches. The reason the broach used in the first operation is of the built-up type is that this broach, if made solid, would require a heavy and expensive piece of tool steel; moreover, as various sizes of housings must be finished, it was decided to make each broach cover as many sizes as possible. To this end, the broaches are made in halves, permitting the insertion of filler-blocks of different thicknesses between the halves when wide cuts are to be made. Thus, in Fig. 57, filler-block *C*, of machine steel, separates the halves of the broach

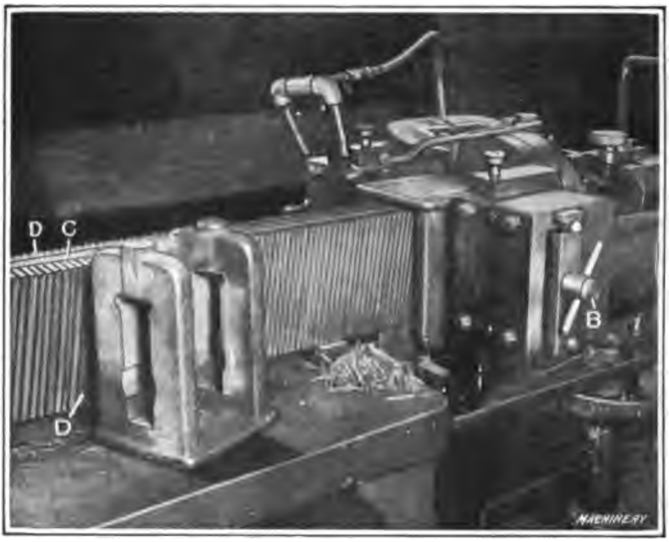

Fig. 56. Close-range View of Broach and Work

to the required size for broaching the housing shown. By substituting thicker or thinner filler-blocks, larger or smaller sized housings may be handled with the same broach. In the top and bottom faces of the filler-block are grooves that engage guide-blocks in the head of the machine, and thus the action of the broach is effectively controlled. The average machining time for finishing the housings by this method is fifteen minutes, as contrasted with two hours and a half for milling.

Broaching Operations on One-pounder Guns. The broaching machine shown in Fig. 58 was developed for broaching

the breech opening and also the rifling grooves of one-pounder guns. Special tool equipments and fixtures are provided for each broaching operation so that it is possible to broach the breech opening and the rifling grooves on the same machine. The design of the fixtures is such that the change from one operation to the other can be made very quickly.

The machine is shown with the fixture and a one-pounder gun mounted in place ready for broaching the rifling grooves in the barrel. The same fixture can also be adapted

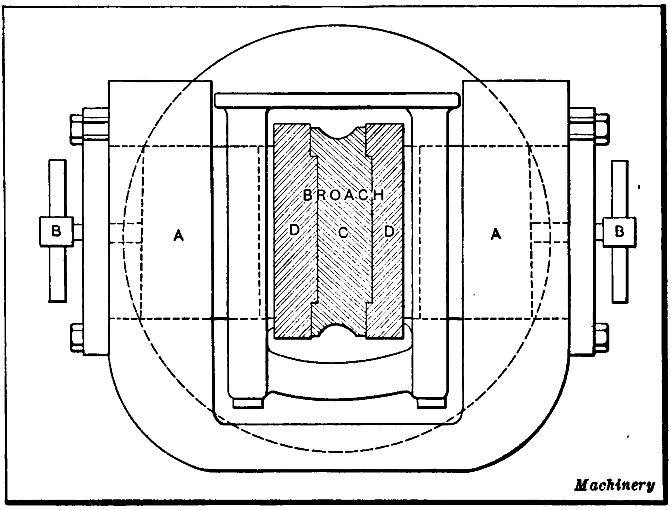

Fig. 57. Broach Section and Details of Work Support

for broaching the breech opening. The broaching of the rifling grooves is done in two operations by the use of a roughing and a finishing broach. The actual length of rifling is 44 inches, as will be noted by referring to the drawing shown in Fig. 59. An enlarged section of the rifling grooves is shown in Fig. 61 from which it will be seen that they are approximately 0.016 inch deep and are twelve in number. The spiral formed by these grooves is right-hand and the lead is one turn in 40 inches. This rifling operation is accomplished by means of a master bar which gives the initial spiral to the cutting tool. The

broaches used are also milled to correspond with the lead required. The master spiral bar is pulled by means of a roller thrust bearing and operates through a spiraling block that causes the bar to rotate. The gun is mounted on a carriage and clamped so as to hold it in perfect ailgnment and also prevent it from revolving. By referring to Fig. 58, it will be noted that there is a large flexible tube and pipe in the oil-pan under the front end of the machine. The pipe is slipped over the end of the broach and into the bore of the gun which at this end is large enough to admit the pipe. The broach is also provided with oil-channels so that

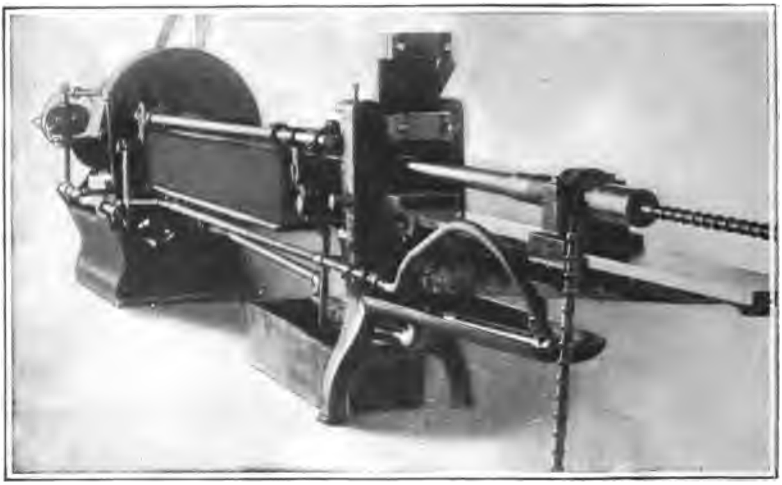

Fig. 58. Special Broaching Machine with Fixture and One-pounder Gun in Place Ready for Broaching Rifle Grooves

every pocket between the cutting teeth of the broaches is filled with oil as it enters the work. The oil is constantly agitated by the high pressure under which it is forced. This results in a very smooth finish, as it prevents the chips from being cut dry and welding to the face of the teeth. The time required for broaching the rifling grooves is approximately fifteen minutes.

Fig. 60 shows the front end of the broaching machine with the fixtures and work mounted in position for broaching the breech opening. The work *D* rests on the bottom *F* of tilting head *A* and is held in place by clamps *B*. The

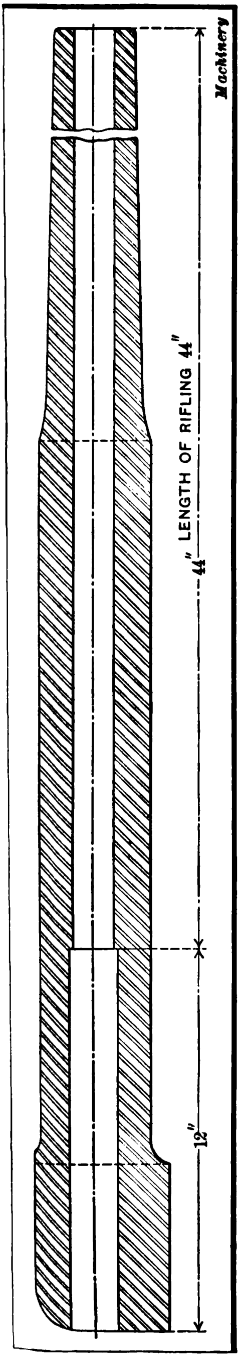

Fig. 59. Barrel of One-pounder Gun

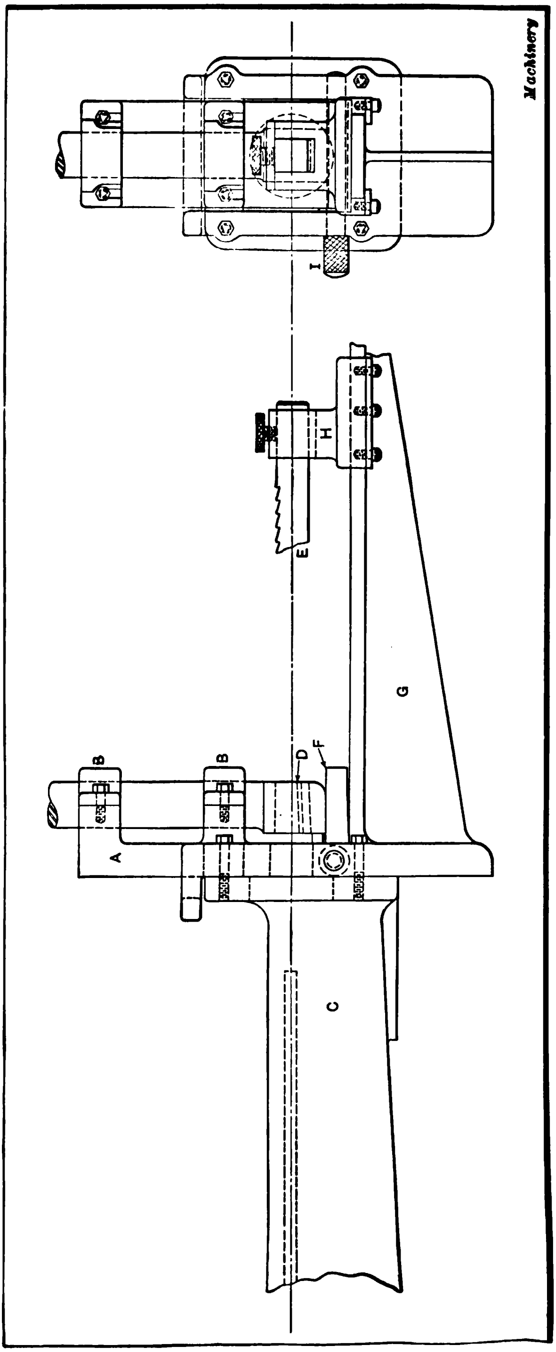

Fig. 60. Front End of Broaching Machine with Fixture and Gun-barrel mounted in Place for broaching Breech Opening

tilting head *A* can be thrown forward or allowed to pivot on pin *I* to give the proper angle for broaching the tapered portion of the breech opening. The casting *G* is the fixture proper which is bolted to the end of the machine *C*. The broach carriage *H* supports the end of broach *E*.

Fig. 62 shows the eleven different operations required in finishing the breech opening, starting from a round hole 2.5 inches in diameter. This hole is bored at an angle of approximately 5 degrees and the first nine operations are performed with the work held at this angle. The dimensions show the amount of material removed at each operation. It will be noted that on the first five operations the width of the rough-broached hole remains the same, namely 2.340 inches, and that the stock removed is all on the top and bottom. Operation 6 is a sizing operation finishing the width of the hole which represents the size between the two splines on the finished pieces. Operations 7, 8, and 9 are confined to removing material on the width of the hole stepping round the two splines, the ninth operation being a sizing operation which finishes the two splines. Operations 10 and 11 are accomplished by means of a T-shaped broach guided against a tapered block. Fig. 63 shows the eleven broaches employed. In this illustration is also shown a steel block that has been broached with this set of tools. The finished size of this broached hole is 2.756 by 2.857 inches. Fig. 64 shows the inside of a finished barrel as it appears when viewed from one end.

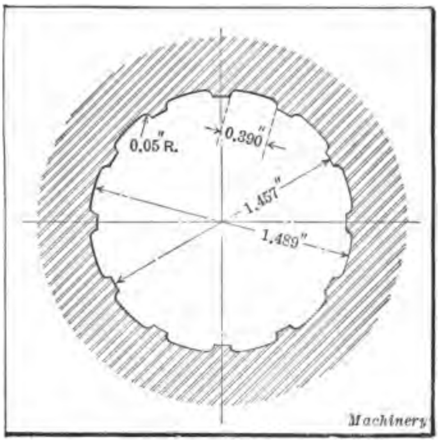

Fig. 61. Section of Gun-barrel which has Twelve Right-hand Spiral Grooves of Uniform Twist making One Turn in Forty Inches

Quick-action Broach Fixture. The fixture shown in Fig. 66 for holding broaches in a broaching machine is simple in

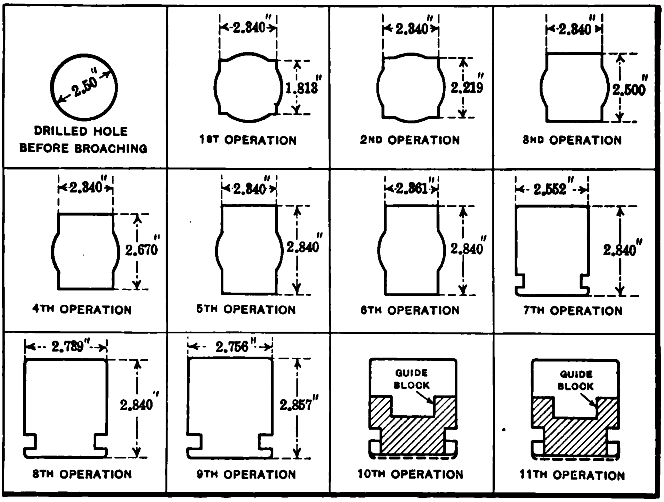

Fig. 62. Eleven Broaching Operations for finishing Breech Opening

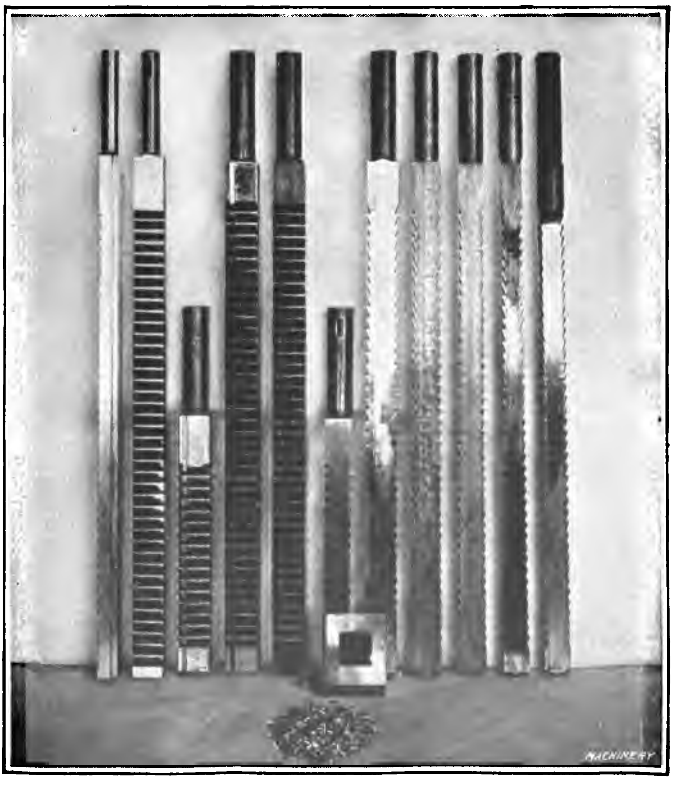

Fig. 63. Broaches employed in Eleven Broaching Operations on Gun

construction, may be easily operated, and will always locate the broach in the right position. The illustration shows the fixture at *A* in an unlocked position, with the clamping ring *C* moved back, the cap removed, and the broach withdrawn. The view *B* shows the cap in position at *E*, holding the broach by means of the ring *C*, just as it would appear when at work. The body *F* and the cap *E* are made of machine steel. It will be noticed that a section is milled out of the body into which the cap fits. By referring to the end elevation of the assembled view, it will be seen that the outline of the cap is made to conform to that of the body, and that a flat *J* is provided on the top against which the screw *D* bears. When the cap is placed in position, the ring *C* is a sliding fit over both parts.

Fig. 64. Inside of Finished Barrel as seen from One End

In making the fixture, the cap is assembled with the body, the hole for receiving the threaded end of the broach is tapped, and then a clearnce represented by *G* is provided so that the pressure produced by screw *D* holds the broach securely in place. The outer end of the tapped hole for the broach is provided with a clearance as represented in the illustration by *W*, so that the broach may be lifted up and removed after the collar has been released and moved back. This feature eliminates the necessity of unscrewing the broach and thus saves much time. The broach is slotted as shown at *H*, and a pin, which engages this slot for locating the broach is provided in the body as shown at *K*. It is not necessary to use a gage in connection with this fixture to locate the broach properly. The fixture is particularly adaptable for use on small work. On such work it is preferable to have a fine-pitch thread for the broach, which

will give greater strength through increasing the area of the cross-section at the root of the thread.

Planish-broaching a Transmission Gear. A square-hole transmission gear of the kind illustrated in Fig. 67 is almost

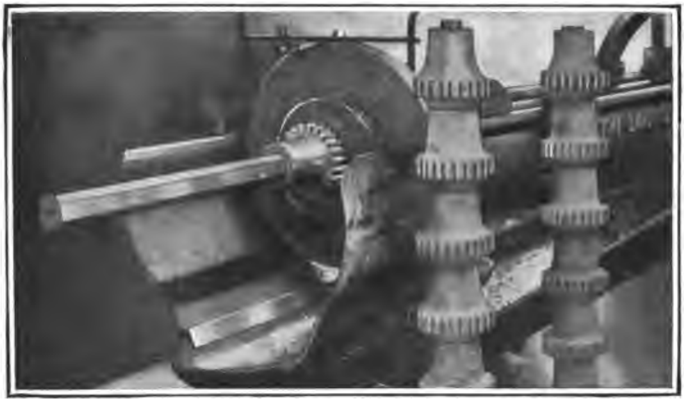

Fig. 65. Planish-broaching Operation on Transmission Gears

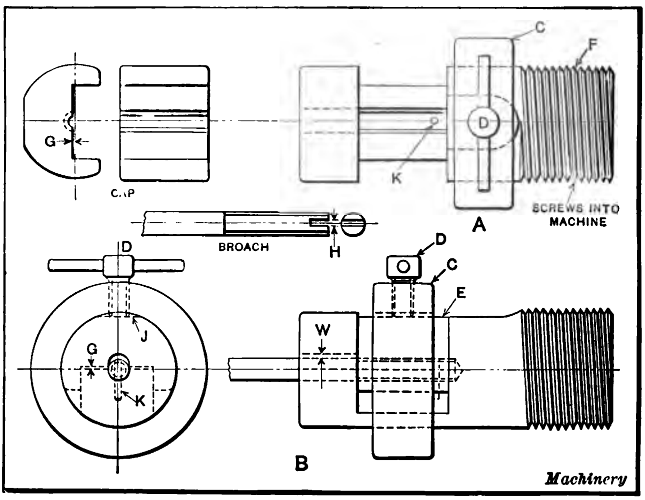

Fig. 66. Fixture for holding Broach in Broaching Machine

sure to close in when hardened. More than that, this closing in is almost sure to be unequal on account of the varying thickness of metal surrounding the hole at different points. For instance, this particular gear, in hardening, will close

in only slightly at the thin end, but will close in considerably at the thick section, owing to the contraction of the heavier mass of metal at this end. The result is that the gear will not slide freely without being machined to fit the shaft after hardening. Grinding the part to suit is a slow operation and not a very satisfactory one, so the American La France Fire Engine Co., Elmira, N. Y., accomplish it by planish-broaching. The planish broach is illustrated in Fig. 65. While there were no teeth on this broach, it was slightly relieved at certain points in order that the pull would not be excessive. All sections of the hole are reached by the broach, but not at the same time. The first section of the broach enters the shrunken hole easily; the next section expands the hole in one direction; the third expands the hole in the other direction; and the last gives a final shaping to all four sides of the hole.

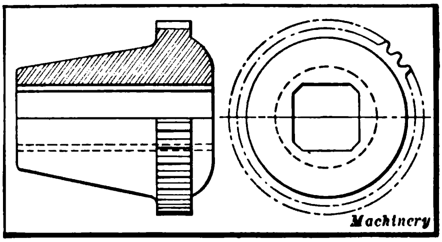

Fig. 67. Gear to be planish-broached

It is necessary to expand the gears about 0.004 inch at the thick section in order to straighten the hole, but to maintain this expansion permanently the broach must be made so that it will compress the stock about 0.008 inch. This makes allowance for the springing back of the metal after being expanded. A lubricant is used to prevent the broach from tearing the sides of the hole.

Broaching Teeth of Spur Gears. Various details in connection with the tools and method used for broaching spur gear teeth on the outside of a small brass pinion are shown in Fig. 69. Briefly, the process is one of forcing the gear blanks through a series of serrated plates which are progressively arranged so that each plate takes off a predetermined amount of material—in short, broaching the gears with external broaches or dies.

An interesting feature in the process is the manufacture of the die-plates. A blank *A* is turned up to form a series

of cylindrical steps, the smallest of which is used for the first die-plate, while the intermediate and largest steps are used to produce the other plates. After the cylindrical work has been done on the cutter blank the teeth are milled to

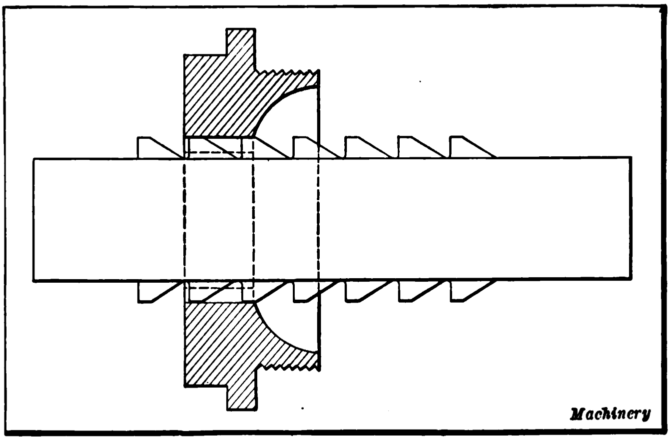

Fig. 68. Broaching Two Keyways Simultaneously in a Turret Lathe

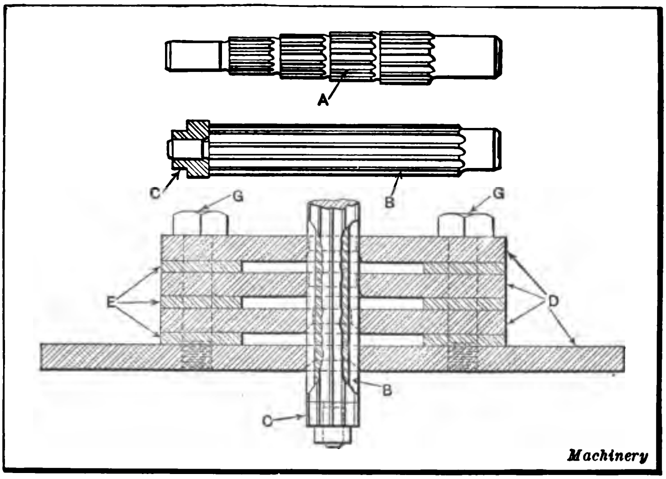

Fig. 69. Broaching Dies for cutting Spur Gear Teeth

correspond with the pitch of the gear required and the cutter is hardened ready for use. The lower illustration in the figure shows the assembled broaching plates *D*. These plates are broached by the cutter *A* so that they operate

on the work progressively, the upper and intermediate plates each taking out a small amount of metal while the lower one finishes the work. The spacing plates *E* which are interposed between the die-plates allow the chips to work out and also provide air space so that the heat generated by friction will radiate readily. The plates are made of machine steel and are carburized and hardened, after which the upper surfaces surrounding the holes are ground to a cutting edge. The plates are bolted together by the bolts *G*, suitable dowels being used to keep them in alignment. It is claimed that this process can also be applied to a bar from which the pinions can be cut off after they have been machined.

Broaching Keyways in a Turret Lathe. The time of manufacturing the brass union parts illustrated in Fig. 68 has been reduced by combining a broaching operation with the turning operation. The part is made from a casting, and the machining consists in turning and then broaching two keyways on opposite sides of the central hole. These keyways are 3/32 inch deep and 3/32 inch wide. The two operations were formerly conducted in different departments, and by combining them the cost of production has been greatly reduced. The part is machined on a Warner & Swasey turret lathe and is greatly facilitated by the use of an air chuck. After the turning has been done and before the piece is taken from the chuck, the operator inserts a small broach in the central hole of the piece and, with a "pusher" on the turret, forces the broach through, cutting the two keyways as shown. The broaching is done with a broach-travel of about two inches, and the action of the turret pushes the broach entirely through the piece so that when it is released from the air chuck the broach drops out with it. In the illustration, the broach is shown part way through the work.

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